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Chapter 9

TECTONIC AND CLIMATIC RHYTHMS AND THE DEVELOPMENT OF SOCIETY

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ABSTRACT

The author discusses the short-period (years to decades) and medium-period (hundreds to thousands years) variations of climatic and tectonic activity and their influences on the human history and recent life. At a regional scale, it is demonstrated that for the last 170 years periodic changes of the Caspian Sea level are the combined result of the water balance variations (mainly caused by climatic changes) and the recent tectonic activity partly manifested by seismicity. The influence of active tectonics consists in the integral effect of various deformations producing changes in the Caspian reservoir volume. Phases of the sea-level fall correspond to the growth of seismicity under the Caspian basins that indicates the extension and sinking of the reservoir. Phases of the sea-level rise correspond to the growth of seismicity under the adjacent uplifts and their slopes that indicates transverse shortening of the reservoir and a decrease in its volume. The climatic and tectonic processes influence the Caspian level mainly in the same direction. The global observations show that the 11-yr and multiple-of-11-yr cyclicity is the most significant among the recent short-period variations of climatic and tectonic activity. This cyclicity influences the economic activity of the society.

The ~1,200-yr (~1,800-yr in one case) cycles are the most important among the medium-period variations of climatic and tectonic activity (i.e., fault movements, earthquakes, and volcanism) in the Middle and Late Holocene. These cycles contributed to the historical crises, which were characterized by social unrest and mass migrations, and changed the balance of political forces. On the other hand, the crises determined breakthroughs to new technologies and new forms of economic and political relations. The crises were manifested in the Alpine–Himalayan orogenic belt and East European Platform. Perhaps they covered the entire Northern hemisphere.

Synchronism of climatic and tectonic events in both short- and medium-term oscillations is possibly caused by the difference in the rotational velocity of the liquid outer core and mantle (the dominant factor), periodic changes in the Earth's orbital parameters, as well as solar activity. Multiple-of-11-yr cycles correlate with the periodic changes in solar activity, whereas the 1,200-yr cycle is associated with the precession of the geomagnetic axis around the Earth's rotational axis. The short- and medium-period variations of climatic and tectonic activity should be considered in planning the sustainable development of the society.

Keywords: oscillations; seismicity; sea level; climate; cycle; history.

9.1. Introduction

The development of humanity was not a continuous progress. Historical documents and archaeological data demonstrate epochs of rise and fall in the development of individual primitive societies, later states, and ethnoses. Climatic and geodynamic activity, manifested by tectonic movements, earthquakes, and volcanism, varied within the historical time with rhythms of various frequencies. For the contemporary human life and development of the society during the stage of the producing economy, only natural rhythms with periodicity from several years to several thousand years were important. The author differentiates (a) short-period variations with the frequency of years to decades, and (b) medium-period variations with the frequency of several hundred to several thousand years, distinguishing them from the long-period rhythms with periodicity of several ten thousand years and more. The short-period variations can be studied in detail for the last 100–150 years only. They influence the contemporary life and should be considered in construction projects, land use, agriculture, and people's security. The medium-period variations can be studied in some regions for all of Middle and Late Holocene time. They have influenced the development of the society and should be considered in long-time economic planning, geopolitical forecasts and constructing the future sustainable development of the humanity. The short- and medium-period environmental variations and their influence on humans and the society are discussed in this chapter.

9.2. Short-Period Variations

9.2.1. Contemporary Variations of the Caspian Sea Level

9.2.1.1. Role of Climatic Changes

Frequent variations in the Caspian Sea level have been recorded at gauging stations from the 1830s (Varushchenko et al., 1987; Lilienberg, 1994; Klige et al., 1998). Until 1930 (almost a hundred years), the level varied between -26.6 and -25.6 m (Figure 9.1a). In 1930–1940, it fell to -27.9 m and continued to fall with small variations down to -28.8 m in 1976. In 1978, the level started to rise and reached -26.5 m in 1997. The rise stopped in 1998. A small fall in the level has been recorded for the last ten years.

The water balance in the Caspian Sea in the 20th century was studied to explain the level variations by climatic changes; water losses in the contributing rivers were also considered (Varushchenko et al., 1987; Klige et al., 1998; Kaplin and Selivanov, 1999). The Volga River is the main contributor to the Caspian water (65–70% of the total input), other rivers offer 10–15% of the total input, and precipitation provides under 20%.

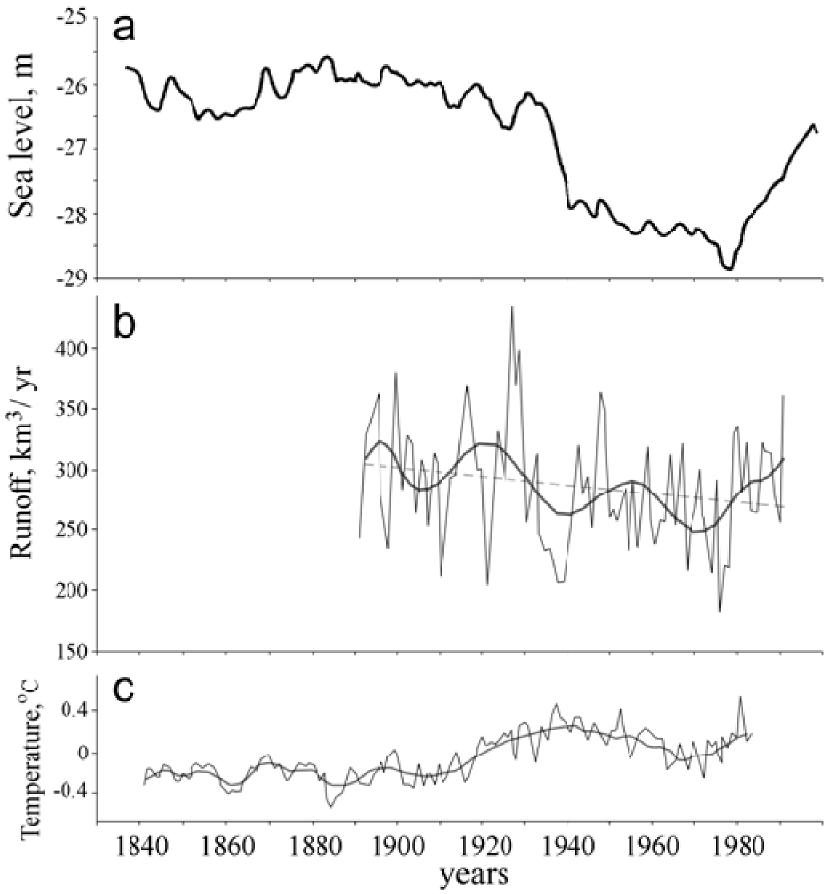

Figure 9.1. Relationships between (a) changes of the Caspian Sea level; (b) variations of the Volga River runoff, thick and dotted lines represent low-frequency and trend components of the variations; and (c) anomalies of the average annual air temperature in the Northern hemisphere, thick line represents low-frequency component of the deviations. The figure was compiled using data from (Lilienberg, 1994; Kaplin and Selivanov, 1999; Klige et al., 2000).

The Caspian water output is mainly composed of evaporation: about 95% from the main basin and about 5% from the Gulf of Kara-Bogaz-Gol. Values of the Caspian water balance components have varied in the 20th century. The average annual standard deviations of the average values reached 18% for the Volga runoff, some 30% for runoff from the other rivers, 20% from atmospheric precipitation, 9% from evaporation from the main basin, and 60% from evaporation from the Kara-Bogaz-Gol, where the large technogenic changes occurred (Getman, 2000). To a first approximation, changes of the Caspian level correlate with these variations (Figure 9.1).

However, there are some essential deviations. For example, a long-term rise of the level in 1978–1997 is not satisfactorily explained. The evaporation and its changes are estimated by indirect manifestations only (cloud, air and water temperature, etc.); those estimates vary from 10 to 20% (Getman, 2000). Changes in the submarine groundwater discharge into the sea are not considered. Its contribution is estimated at about 5% of the Volga runoff. Therefore, although the water balance fluctuations play a significant and possibly leading role in the Caspian level changes, other causes of these changes should be considered. Indeed, using repeated geodetic measurement data, Lilienberg (1994) found a change in a recent motion regime in the adjacent regions near 1978, when the Caspian level started to rise after the long-term fall. However, information on tectonic processes in the Caspian *per se* may be obtained only by an analysis of regional seismicity.

9.2.1.2. Seismotectonic Provinces of the Caspian Region

Using a seismological data set (Moinfar et al., 1994; Kondorskaya and Ulomov, 1999; National Earthquake Information Center, 2004), we carried out a comparison of the Caspian level changes and tectonic processes partly reflected by variations of seismicity in various seismotectonic provinces of the Caspian region (Ivanova and Trifonov, 2002). More than 1,200 earthquakes were analyzed for the Caspian region, between 36.5° N and 44° N and between 47.5° E and 54.5° E (Figure 9.2). The annual values of the seismic energy released in provinces were calculated using the following formula (T.G. Rautian, personal communication, 2000):

$$\lg E = 4 + 1.8 \cdot M_{LH},, \qquad (9.1)$$

where E is seismic energy calculated in J, M_{LH} is earthquake magnitude.

Seismotectonic provinces in the region (Figure 9.2) were delineated using the following criteria: (a) structure of the Earth's crust (Krasnopevtseva, 1984; Artyushkov, 1993), (b) peculiarities of the Pliocene–Quaternary tectonic development (Milanovskii, 1968; Rastsvetaev, 1973; Kopp, 1997; Leonov et al., 1998; Leonov, 2007), (c) patterns and kinematics of active faults (Trifonov, 1983; Trifonov et al., 1986, 2002), and (d) location of seismic focal zones and their dynamics during the epoch concerned (Figures 9.2 and 9.3). Focal zones are mainly situated in neotectonic structural boundaries characterized by high gradients of geophysical parameters, such as gravitational field and pattern of seismic wave distribution, and Late Cenozoic movements.

The region occupies a part of the Epi-Paleozoic Scythian–Turanian Plate, rebuilt more or less by the Cenozoic movements, and areas of the Alpine tectonics (Ivanova and Trifonov, 2002). The Middle Caspian, the adjacent coasts, and the eastern part of the South Caspian basin (provinces I, II, and VII) belong to the Scythian–Turanian plate, whereas the western and central part of the South Caspian and adjacent coastal areas (provinces III−VI) belong to the Alpine structural belt.

The province I (Figure 9.2) includes the eastern and southeastern parts of the Pliocene–Quaternary uplift of the Great Caucasus (Figure 9.3a) and the Derbent foredeep in the western part of the Middle Caspian Sea. Thickness of the sedimentary cover exceeds 14 km in the foredeep (Figure 9.3b). More than 5 km of it belongs to the Pliocene–Quaternary (Leonov et al., 1998). The main seismic zone with earthquakes with surface-wave magnitudes (M_S) up to 6.3 and focal depths down to 110 km is located along the southwestern slope of the foredeep.

Weak Late Cenozoic movements characterize the larger part of the province II (Figure 9.2). The Kara-Bogaz dome with the thinned Earth's crust (Figure 9.3c) is situated in the south of the province. The Northern and Southern Balkhan fault zones form great structural contrast in the southern side of the dome and correspond to the Krasnovodsk–Balkhan seismic zone with the strongest Kazanjik (1946, $M_S = 7$) and Great Balkhan (2000, $M_S = 7.4$) earthquakes.

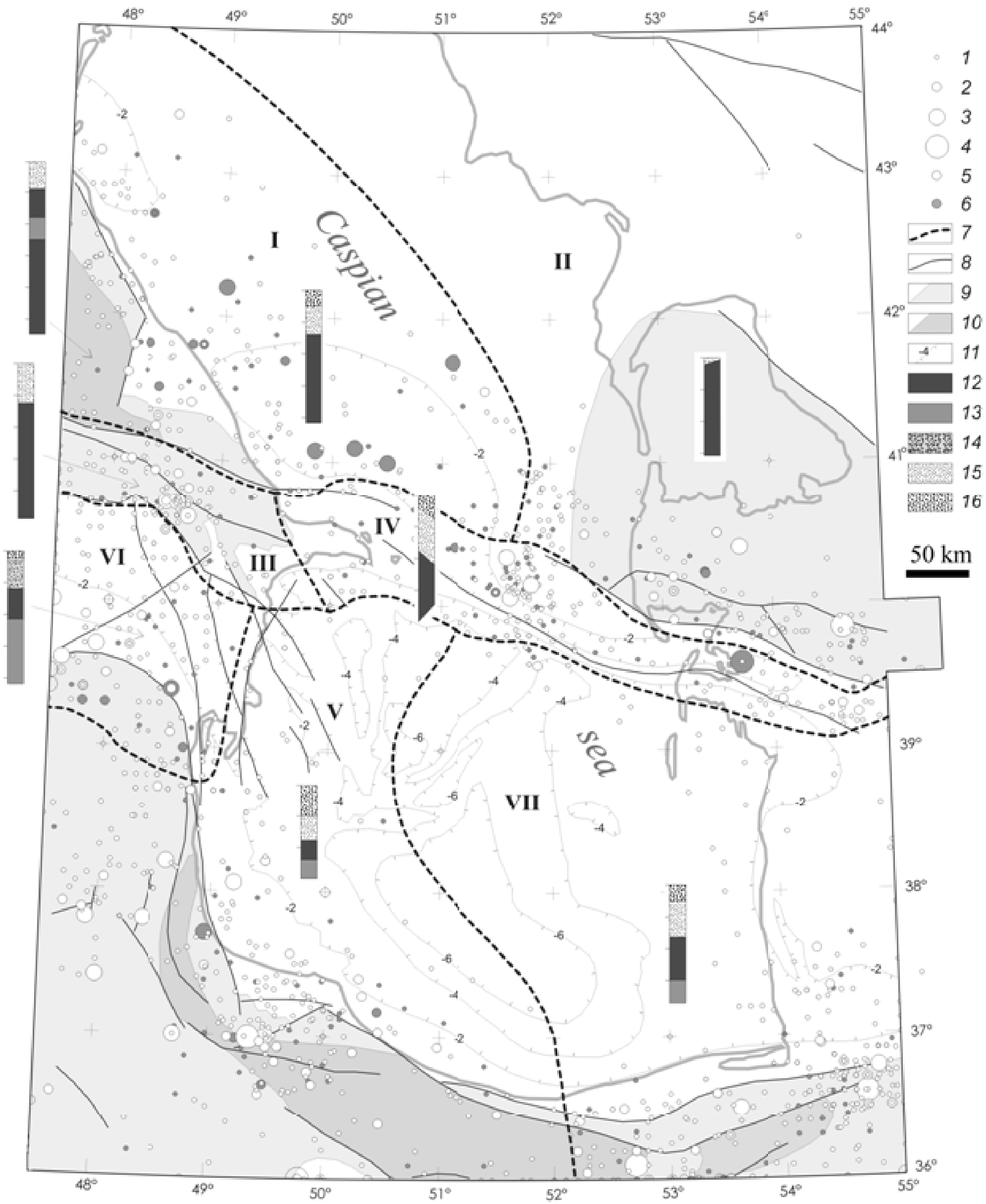

Figure 9.2. Seismotectonic provinces I–VII and earthquake epicenters in the Caspian region (Ivanova and Trifonov, 2002): 1–4 are M_S: 1 – <5, 2 – 5–5.9, 3 – 6–6.9, 4 – ≥7; 5 and 6 are depth of hypocenters of earthquakes: 5 – ≤33 km, 6 – >33 km; 7 – the province boundaries; 8 – active faults; 9–11 – areas with different regimes of the Pliocene–Quaternary vertical movements: 9 – a moderate uplift, 10 – an intensive uplift, 11 – subsidence (isopachs of the Pliocene–Quaternary deposits are shown with the interval of 2 km); 12–16 – principal sections of the Earth's crust: 12 – the basement, 13 – a waveguide within the basement, 14 – the Jurassic–Cretaceous volcanic unit, 15 – the sedimentary cover or its pre-Pliocene part, 16 – Pliocene–Quaternary part of the cover.

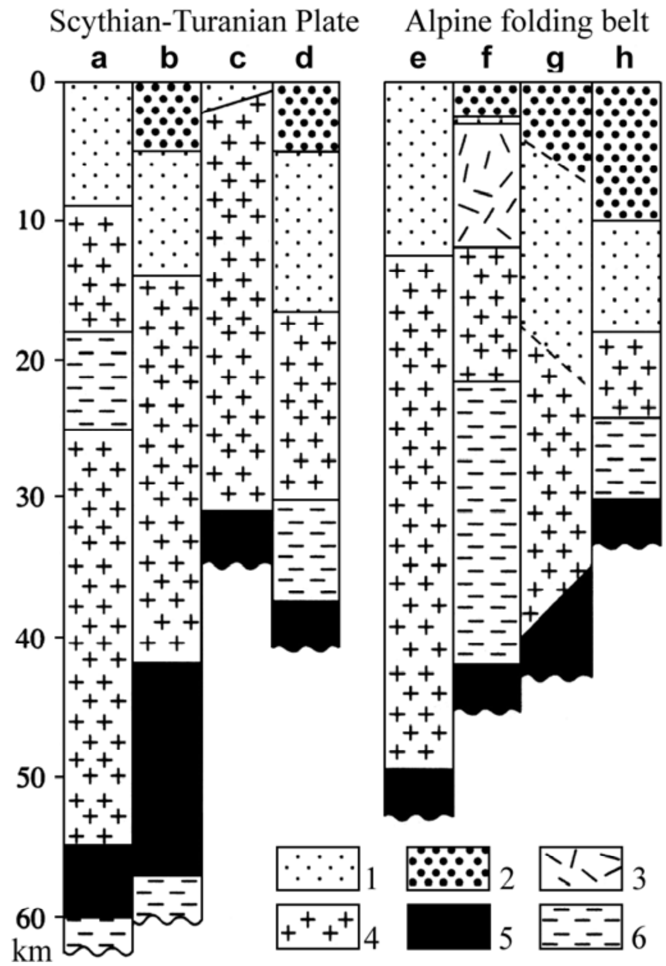

Figure 9.3. Schematic deep sections of the provinces in the Caspian region: (a) province I, the coastal part of the Eastern Caucasus (Krasnopevtseva, 1984); (b) province I, the Derbent basin (Krasnopevtseva, 1984; Leonov et al., 1998); (c) province II (Garetsky, 1972); (d) province VII (Artyushkov, 1993; Leonov et al., 1998); (e) province III (Krasnopevtseva, 1984); (f) province VI (Krasnopevtseva, 1984); (g) province IV (Leonov et al., 1998; Ivanova and Trifonov, 2002); (h) province V (Artyushkov, 1993). 1 – the sedimentary cover or its pre-Pliocene part only, 2 – the Pliocene–Quaternary part of the cover, 3 – the Jurassic–Lower Cretaceous volcanic unit, 4 – the crustal basement, 5 – the upper mantle, 6 – crustal and upper mantle waveguides.

In the province VII (Figure 9.2), the thickness of the crustal basement of the Scythian–Turanian type is reduced to 15–20 km beneath the eastern part of the South Caspian basin (Figure 9.3d). The Gorgan foredeep with the thickened sedimentary cover is situated in the south of the province, in front of the Allah Dagh and Eastern Alborz Ranges. Earthquakes with $M_S \geq 6$ took place there.

The province III is a part of the zone of the Southern Slope of the Great Caucasus (Figure 9.2) contacting a thicker crust of the Great Caucasus. The abrupt change of the crust thickness in this province was caused by sedimentation of deep-water facies in the Late Mesozoic, Paleogene, and Early Miocene on the thinned Paratethys crust. In the Late Cenozoic, the crust thickness was increased by the subsidence of the Lower Kura basin, folding, and thrusting in the Southern Slope zone (Krasnopevtseva, 1984; Leonov, 2007) (Figure 9.3e). The strongest Shemakha earthquake ($M_S = 6.9$) happened in 1902.

The province VI (Lower Kura basin – Figure 9.2) is similar to the province VII (Figure 9.3f). The main focal zone is situated in the southern part of the province, on its boundary with the uplifted Talysh Ridge, and is marked by active faults (Trifonov et al., 2002).

The Apsheron Threshold zone (province IV) is formed by en echelon system of folds in the sedimentary cover and corresponds to the deep-seated fault zone between the Epi-Paleozoic continental crust of the Middle Caspian and the thinned crust of the South Caspian basin (Figures 9.2 and 9.3g). The active fault zone strikes along the Threshold and sense of motion on the faults changes from the west to the east. It is mainly reverse in the Great Caucasus and dextral in Turkmenistan (Kopp, 1997; Rastsvetaev, 1973; Trifonov, 1983; Trifonov et al., 1986, 2002). The 1995 Krasnovodsk earthquake ($M_S = 7.9$, the focal depth was 55 km) was the strongest in the region. The 1986 and 1989 events with $M_S \geq 6$ happened in the Central Caspian near the Moho surface or lower.

The province V occupies the central and western parts of the South Caspian and adjacent uplifts of the Talysh and Western Alborz Ridges (Figure 9.2). These parts of the South Caspian are the deep basin (bathymetric depths are down to 1,000 m), where the crustal basement is thinned to 8−10 km (Figure 9.3h). Thickness of the folded sedimentary cover reaches 20 km (Artyushkov, 1993; Leonov et al., 1998). No less than half of the cover belongs to the Pliocene–Quaternary: thickness of merely the Late Pliocene and Quaternary exceed 6 km in some places (Figure 9.3h). The longitudinal folds and thrusts dominate in the neotectonic setting of the Talysh and Western Alborz. However, the thrust component of motion combines with dextral component in the Talysh and with the sinistral component in the Western Alborz (Berberian, 1976; Berberian et al., 1992; Trifonov et al., 2002). The main seismic zones are situated on the boundary of the deep basin and the adjacent uplifts as well as in the uplifted ridges. The 1990 Rudbar earthquake ($M_S = 7.4$) was the strongest in the Alborz.

Therefore, the seismicity is concentrated in the deep neotectonic basins in the provinces I, III, VI, and VII (the Derbent and Gorgan foredeeps and Lower Kura basin). However, it is also typical for slopes or axes of the Late Cenozoic uplifts in the provinces II, IV, and V. This difference is important for the interpretation of relationships between variations of seismicity and the Caspian level changes.

9.2.1.3. Relations between Seismicity in the Caspian Region and the Caspian Level Fluctuations

The strongest earthquakes give the main contribution to the release of seismic energy. Six earthquakes with $M_S \geq 7$, seven earthquakes with $M_S = 6.5–6.9$, and twenty earthquakes with $M_S = 6.0–6.4$ were recorded in the region from 1835 until now. Rise of the Caspian level (or deceleration of its fall) were registered after all earthquakes with $M_S \geq 6.5$, although the rise took place only a year after the Buyin Zara event (1962, $M_S = 7.2$), which is the most remote from the Caspian. The rise reached 30 cm after the 1895 Krasnovodsk earthquake ($M_S = 7.9$), 20 cm after the 1946 Kazanjik earthquake ($M_S = 7.0$), 10 cm after the 1890 Gorgan earthquake ($M_S = 7.2$), and 8 cm after the 1902 Shemakha earthquake ($M_S = 6.9$). The 1990 Rudbar event ($M_S = 7.4$) was accompanied by acceleration of the rise. After earthquakes with $M_S = 6.0–6.4$, the sea-level rise was registered for all events with epicenters in the Caspian

Sea and nearby, and only for 60% of events happened in the region far from the sea. These effects of the strongest earthquakes are probably the results of permanent deformation (leaking) inside the sea bottom.

Therefore, direct influence of the strongest earthquakes can produce the small-scale and probably temporary rise of the Caspian level. However, earthquakes and released seismic energy are only a partial reflection of recent tectonic deformation. Contribution of seismic displacements to the total tectonic motion varies and depends on geological setting. For example, the contribution is more than 50% in central and northern Iran with its thick consolidated part of the Earth's crust (Jackson and McKenzie, 1988). This estimate can correspond to the contribution of seismic movements in the provinces II and partly VII of the Caspian region. However, in deep sedimentary basins like the Mesopotamian foredeep and the External Zagros, similar to the Derbent foredeep and the South Caspian basin, the calculated contribution is less than 10% (Jackson and McKenzie, 1988). It is probably even less in the lower crust and the upper mantle. If one considers these peculiarities, the registered seismicity can manifest much bigger tectonic movements than the earthquakes themselves, and the role of tectonics in the Caspian level changes can be essential, particularly in the Derbent foredeep and the South Caspian basin.

To estimate relationships between the Caspian level changes and variations of seismicity in the seismotectonic provinces, we ignored small fluctuations and defined the amount of earthquakes with $M_S \geq 4.9$ in each province during the seven principal stages of the level changes (Ivanova and Trifonov, 2002). These were:

- 1837–1853 stage of the level fall,
- 1854–1883 stage of the level rise,
- 1884–1910 stage of the relatively stable level,
- 1911–1929 stage of the weak fall,
- 1930–1940 stage of the quick fall,
- 1941–1977 stage of the weak fall, and
- 1978–1997 stage of the quick rise of the level.

The bigger amount of the earthquakes was typical for the 1930–1940 stage in the provinces I, III, VI, and VII and for the 1978–1997 stage in the provinces II, IV, and V (Figure 9.4a).

To check this difference more accurately, we used the parameter of seismic power, that is, the average annual value of released seismic energy in the provinces during the stages. The maximum seismic power was typical for the 1884–1910 stage of the stable highest position of the sea level. However, the further seismicity in the provinces I, III, VI, and VII and the provinces II, IV, and V were different (Figure 9.4b).

The seismic power decreased in the second group in the 1911–1929 stage ($\lg E$ = 12.6) and became lower than in the first group ($\lg E$ = 14.8). These parameters converged in the 1930–1940 stage. However, later, in the stages 1941–1977 and 1978–1997, seismic power decreased in the first group ($\lg E$ = 14 and 12.9, respectively) and increased in the second group ($\lg E$ = 15.1 and 16.5, respectively).

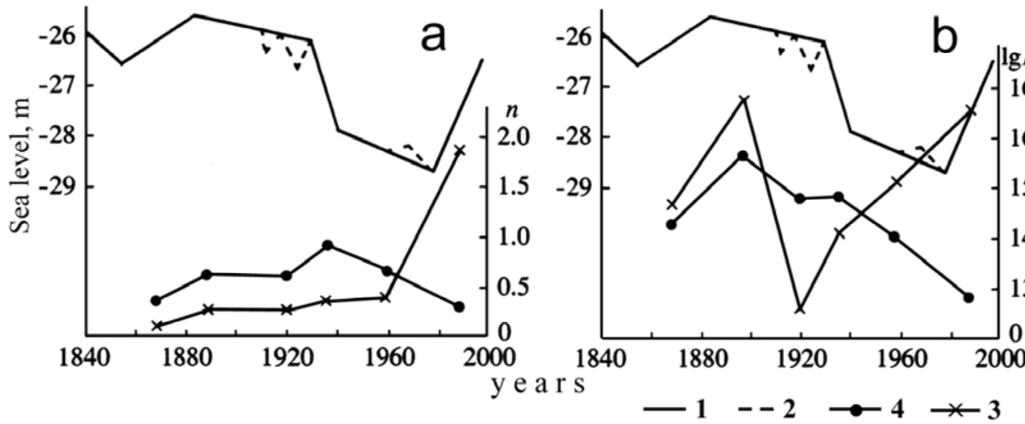

Figure 9.4. Relationships between stages in the Caspian level changes and (a) the number of earthquakes with $M_S \geq 4.9$, and (b) the average annual seismic energy released during these stages (Ivanova and Trifonov, 2002). 1 – Caspian level changes from stage to stage (coarsened), 2 – the highest sea-level variations within the stages, 3 and 4 – the number of earthquakes for each stage divided by its duration (*n*), or the average annual released seismic energy for each stage (lg*E*): 3 – in the provinces II, IV, and V; 4 – in the provinces I, III, VI, and VII.

Since some stages contained episodes of the opposite behavior of the Caspian level, we divided the stages to the phases of the one-way regime of the sea level (rise or fall with rates more than 0.05 mm/yr or stable position with fluctuations with smaller rates) and calculated seismic power of the provinces for each phase. The provinces I, III, and VI demonstrated the maximum release of seismic energy during the phases of the sea-level fall. Province VII showed the same, when we excluded the seismic effect of the strongest 1890 Gorgan earthquake happened in the phase of the stable sea level. In the provinces II, IV, and V, seismic power was usually higher for the phases of rise than for those of fall in the sea level. It is the most evident in the province IV (with effect of the 1895 Krasnovodsk earthquake or without it), where the seismic power grew in 1978–1989, when the sea level rose particularly quickly (Ivanova and Trifonov, 2002). The different seismic behavior of the two groups of the provinces is seen in Figure 9.5, which demonstrates average seismic power of the provinces for all phases of rise (36 yr), fall (60 yr), and stable position (58 yr) of the Caspian level.

The similar regularities were found by an analysis of merely 180 registered earthquakes with hypocenters at depths more than 33 km (i.e., in the lower crust and the upper mantle), although 116 of such deep events took place in 1978–1998. The strongest 1895 Krasnovodsk earthquake reduces the deep seismicity in the southeastern part of the region and the first deep earthquake happened in the Krasnovodsk area only in 1970. Until 1978, the deep seismicity was concentrated in the Derbent and Lower Kura basins and all earthquakes took place during sea-level falls. In 1978–1997, when the sea level rose, the deep seismicity reduced in these provinces and increased around and partly within the South Caspian basin. Therefore, the change of the Caspian level regime in 1978 coincides with the rebuilding of seismicity in the lower crust and the upper mantle that shows influence of the deep-seated tectonic processes on sea-level changes.

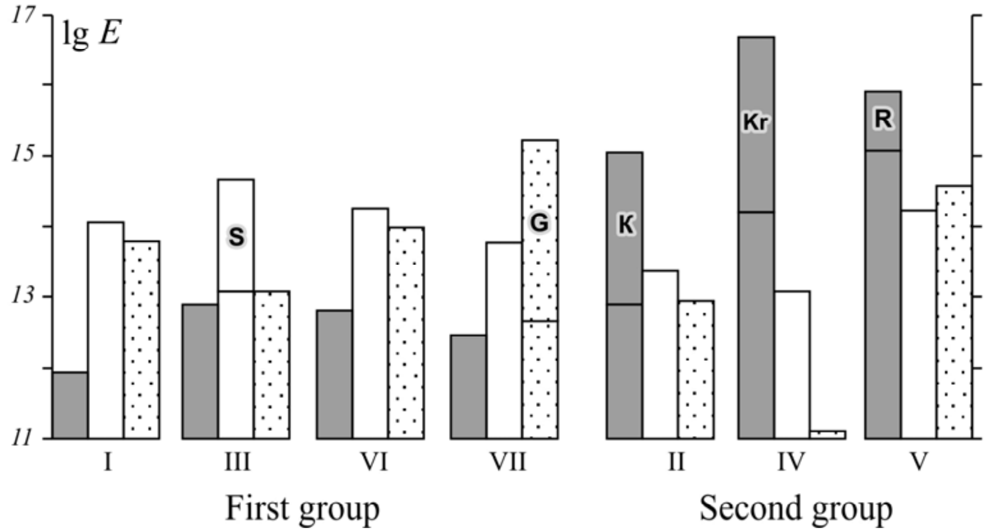

Figure 9.5. Average annual values of the seismic energy released in the provinces I–VII during all stages of uplift (dark gray), subsidence (white), and stability (dotted) of the Caspian level (Ivanova and Trifonov, 2002). Contribution of the strongest earthquakes: G – 1890 Gorgan, K – 1946 Kazanjik, Kr – 1895 Krasnovodsk, R – 1990 Rudbar, and S – 1902 Shemakha.

The represented data show that activity of the seismic zones within the sinking basins (provinces I, III, VI, and VII) coincides with the Caspian level fall, whereas activity of the zones in the slopes of uplifts surrounding the basins (provinces II, IV, and V) coincides with the level rise. The most important is phase opposition of the seismic zones in the Derbent foredeep and around the South Caspian, because seismic displacement in these deep basins represents only small part of their total recent tectonic motion. This regularity permits us to look for influence of recent deformation of the Caspian reservoir on its water level.

The Middle and South Caspian basins and surrounding ridges are neotectonic structures of the Alpine–Himalayan collision belt. Their recent compression is proved both by morphology of the boundary zones between basins and ridges (Milanovskii, 1968; Berberian et al., 1992; Kopp, 1997) and results of the GPS measurement (McClusky et al., 2000). When the compression increases (growth of seismicity around the South Caspian basin), the transverse shortening of the basins takes place, their volume decreases, and the water level rises. It is accompanied in the South Caspian by acceleration of growth of underwater anticlines that resulted in additional rise of the level. When the compression decreases, the Derbent and other basins sink quicker. This process results in the sea-level fall and is accompanied by increasing seismicity within the basins.

This model was confirmed by an analysis of focal mechanisms of earthquakes carried out using 128 events from the catalogs by Balakina et al. (1996) and Mostryukov and Petrov (1994). Space position of sectors of predominant compression (shortening, *P*) and extension (lengthening, *T*) was defined for all the earthquakes within the study area for some temporal interval (Ivanova and Trifonov, 2002). The analysis showed that the 1960–1977 epoch, when the seismicity was concentrated in provinces I, VI, and VII, the transverse horizontal compression decreased. It was vertical in the Derbent foredeep and was trended to the west-north-west direction (along the structures) in the South Caspian. It produced normal faulting, sink of the basins, and the sea-level fall, as the result, in the Derbent foredeep and other basins. However, from 1978, position of *P* and *T* axes became suitable for strike slip but not normal faulting there. The compression axes turned near the South Caspian basin to east-north-east – west-south-west direction, viz. across the structures. This led to an increased transverse shortening and the sea-level rise as a result.

Changes of composition and physical properties of rocks in the lower crust and the upper mantle could accompany the collision deformation. The 16-km thick high-velocity layer was found just beneath the Moho surface in the Derbent foredeep (Krasnopevtseva, 1984). It gives the negative isostatic anomaly (Artem'ev and Kaban, 1986). It is probably caused by eclogitization of the lower crust rocks. The bigger negative isostatic anomaly in the South Caspian shows that the same process could took place there even in the larger scale (Artyushkov, 1993). The process could produce additional sink of the basins and the sea-level fall.

The recent tectonic processes both deform the Caspian reservoir and can influence an amount of the groundwater recharge. Clays predominate in the Caspian sedimentary cover. The clay sediment contains up to 80% water. Its main part is free (interstitial water) and more than 40% is bound by physical and chemical processes (bound water). The free water is removed to the reservoir by loading the upper sediments and porosity of the sediment decreases down to 8–10% in the depth of 1.5 km. This process does not change the sea level. However, under temperature 100–140° C, tectonic stress and loading of the sediments, montmorillonite (main clay mineral of weathering zone and the Caspian sediments) transforms into hydromica (Kholodov, 1983). The bound water released by this process can reach 10% of the primary weight of the rock. The released water produces abnormally high strata pressure. The main part of the Caspian groundwater is concentrated in the South Caspian basin (Leonov et al., 1998). Because of a high rate of sinking, the removing of interstitial water has been incomplete and an abnormally high strata pressure arrives at depths of 5–6 km. The zone of leaking is registered at the depths of 7–12 km. It corresponds to the area of transformation of montmorillonite to hydromica (Kholodov, 1990). A volume of water, which can be released in those depths in the South Caspian, reaches about 10^5 km^3 that is commensurable with the volume of water of the Caspian Sea (about 0.75×10^5 km^3).

The water, released in the abnormally high strata pressure zones, is concentrated in fluid sources and is unloaded in mud volcanoes within the basin and in reservoir beds around it. Formation of new fractures and activation of existed channels during strong earthquakes can unload the fluid source for several months. Even events with $M_S = 5–6$ can produce such hydro-eruptions and epochs of high seismicity can supply the eruption of billions cubic meters of water to the surface. For example, Ivanchuk (1994) estimated the volume of hydro-eruption in the Akhtarma–Poshaly fold, Azerbaijan as 8 km^3 that corresponds to 1/5 of the water volume, which is necessary to give the annual rise of the Caspian level to 0.1 m typical for 1982–1997 (Leonov et al., 1998).

Thus, fluctuations of the Caspian level within the last 170 years are the combined result of the water balance variations caused mainly by climatic changes and the recent tectonic events partly manifested by seismicity. The main contribution belongs probably to climatic variations, but active tectonics also plays an essential role. Its influence consists in the integral effect of various deformations producing a change of the Caspian reservoir volume (sinking of basins, transverse shortening, and growth of local underwater anticlines), and probably variations of the groundwater recharge. The latter can particularly be important in the South Caspian.

The climatic and tectonic processes influence the Caspian level mainly in the same direction, although the author cannot find mutual relations between these two groups of processes. A study of Kaftan and Tatevian (1996) is interesting in this context. They carried out the harmonic analysis of changes of solar activity index and secular variations of the angular rate of the Earth's rotation and compared them with fluctuations of the Caspian level. The model of the level changes, developed with the first six harmonics of the highest amplitudes, both coincided satisfactorily with the actual level variations and allowed these authors to predict the ending of the level rise in 1997 (Figure 9.6). This is a base to suppose that regulating influence of changes of solar activity and the rate of the Earth's rotation causes synchronism of frequent variations of climatic and tectonic activity.

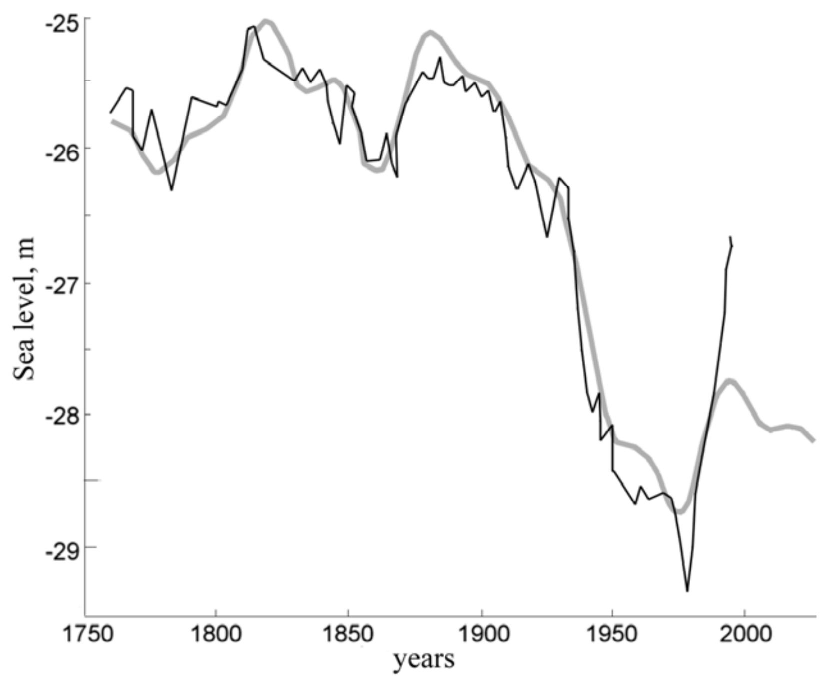

Figure 9.6. Caspian Sea level changes: observed (black) and modeled (gray) (after Kaftan and Tatevian, 1996, © Tatevian, 1996; reproduced with kind permission of the author).

9.2.2. Orbital–Astronomical Regulation of the Contemporary Short-Term Variations of Climatic and Tectonic Activity

Tchijevsky (1938) and his followers (Vladimirsky, 1998) grounded cyclic periodicity of solar activity and geomagnetic disturbance and correlated with them changes of climate, crop capacity, locust invasions, epidemics, and so on (Section 4.2.5). They showed the highest stability of the ~11-yr cycle, corresponding to the average period of the Wolf number (relative sunspot number) variations, and showed the existence of periodicities multiple of the ~11-yr cycle: 5–6, 22, 33–35, and ~90 yr. One can see the 10–11-yr (in average) periodicity of the near-ground air temperature both global and (more evident) in the Northern hemisphere in 1850–1990 on Figure 9.7. Lyatkher (2000) paid attention to changes of duration of the main ~11-yr cycle within the last 250 years and showed that its variations are also quasi-cyclic with a period of 60–100 yr. There are correlations between solar activity cycles and the amount of earthquakes (Tchijevsky, 1938; Sytinskii, 1987), and average time intervals between earthquakes with $M \geq 7$ and the main cycle duration (Lyatkher, 2000). Makarov et al. (1995) found the 9–12 and 5–6-yr cyclicity in time series of the landslide activity in Europe. These cycles manifest a periodicity of moistening, i.e., climatic changes, as well as seismic activity in the Alpine belt, where a significant part of landslides are situated.

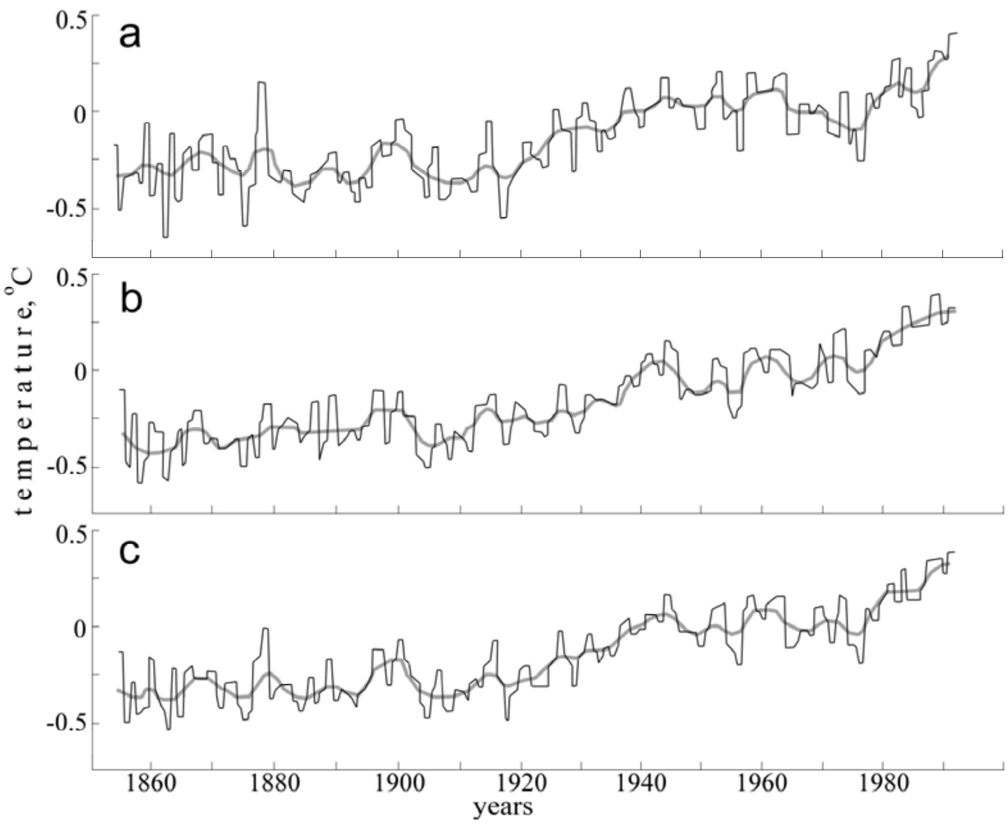

Figure 9.7. Deviations of the annual near-ground air temperature from 1850 to 1990 (thin black lines) from the average air temperature for 1951–1980; thick gray lines are low-frequency components of the deviations: (a) the Northern hemisphere, (b) the Southern hemisphere, (c) the globe (after Losev, 2001, © Losev, 2001; reproduced with kind permission of the author).

For the last 400 years, Levi et al. (2002) showed the existence of global rhythms of maxima of the seismic energy release with the most typical period of 20–30 years and not so clear periods of 45, 90, 150, and 195–200 yr. The phases of maximum release of the energy are late relative to the phases of maximum frequency of earthquakes up to 10 yr. For the last 400 years, the 20–30-yr period is also the most typical for the global volcanic eruption rhythms. The tendency of phase opposition between the seismic and volcanic events was found. The 20–26-yr rhythms is characteristic for accretion of larch in the Baikal region from 1362. The 22–30 and 40-yr cycles were detected for the Baikal level changes for the last 250 years, and the 11, 22–25 and 35–37-yr periodicities were registered for the air temperature variations in the city of Irkutsk from 1881. So, the most characteristic periodicity of the studied natural events is close to, or multiple of the double Wolf cycle (Levi et al., 2002).

Using a catalog of strong earthquakes ($M_S \geq 5.7$) in the Alpine–Himalayan orogenic belt (Trifonov and Karakhanian, 2004), Senko et al. (2004) analyzed temporal variations of the released seismic energy in a region between 15° E and 80° E as a whole and its seismic provinces and zones for the second part of the 19th and the 20th centuries. The catalog was compiled using a set of regional catalogs and papers describing individual historical earthquakes (Kárník, 1968; Shebalin et al., 1974; Poirer and Taher, 1980; Ambraseys and Melville, 1982; Kondorskaya and Shebalin, 1982; Berberian, 1994; Guidoboni et al., 1994; Moinfar et al., 1994; Ambraseys and White, 1997; Papazachos and Papazachou, 1997; Kondorskaya and Ulomov, 1999; National Earthquake Information Center, 2004; Ekström et al., 2006).

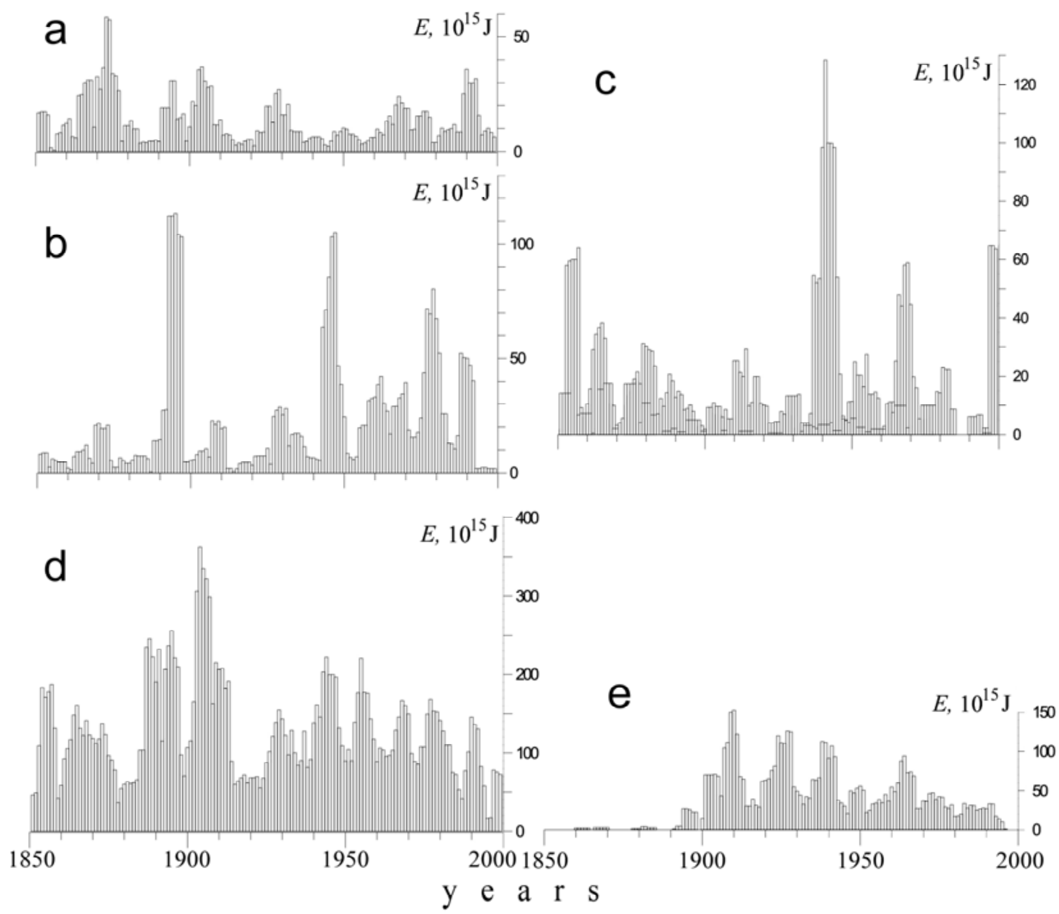

Figure 9.8. The seismic energy E released by earthquakes with $M_S \geq 5.7$ in the second part of the 19th and 20th centuries in (a) Anatolia, the Crete–Aegean, and Carpathian–Balkan regions, depths of hypocenters ≤70 km; (b) the same area, depths of hypocenters >70 km; (c) the North Anatolian zone; (d) the central part of the Alpine–Himalayan collision belt, depths of hypocenters ≤70 km; (e) the same area, depths of hypocenters >70 km. Histograms were plotted with the 1-yr step and smoothed by the 5-yr moving average (Senko et al., 2004).

We determined the released energy by the following formula (F.F. Aptikaev, personal communication, 2000):

$$E = 10^{(8.1+0.9098(M+1.55))}. \quad (9.2)$$

The 10–12-yr cyclicity predominated in the individual seismic provinces and zones of the belt and the 22- and ~15-yr cycles were also found in some of them. An increase in the cycle duration was found before and rarely after the strongest earthquakes. For the region as a whole, these cycles sum up and give the more evident 10–11-yr periodicity (Figure 9.8).

On the other hand, many climatologists recognize links between the frequent climatic variations and fluctuations of the Earth's rotation parameters and, first of all, the angular rate of the rotation. This connection can be mutual because changes of the atmospheric flows and volume of glaciers can influence the rotation rate (Selivanov, 1996).

Gor'kavyi et al. (1995, 1999) compared variations of the annual number of earthquakes and the rate of angular rotation. They distinguished three components of changes in the seismicity: (a) the global 10−15-yr rhythm; (b) a transregional ~3-yr component manifested by the phase opposition for the Northern and Southern hemispheres (a maximum number of earthquakes with $M_b \geq 4$ in one hemisphere corresponds to a minimum number of those in another one); and (c) a regional noncyclic component depending on a local tectonic situation. The studies showed high average values of correlation coefficients between the earthquake number in 1964−1990 and modulus of a time derivative of the rate of angular rotation $|d\Omega / dt|$, viz. its acceleration (Table 9.1). The correlation depends on earthquake magnitude, time intervals, and tectonic situation. The correlation is higher for the 1969−1988 interval than for the others. For the globe, correlation coefficients reach high values (>0.5) only for earthquakes with $M \geq 5$. The correlation is higher for the intermediate earthquakes (the focal depths are 50−240 km) than for the crustal ones. However, no correlations were found for the deepest (>300 km) events in the subduction zones. Therefore, this relationship is just global and decreases with reduction of the studied territory.

Table 9.1. Correlation coefficients between annual number of earthquakes *N* and absolute values of time derivatives of the angular speed of the Earth's rotation $|d\Omega/dt|$ (Gor'kavyi et al., 1999); sample sizes are 27, p ≤ 0.01

Region	Magnitude	Depth, km	Period 1964–1990	1969–1988
			Correlation coefficient	
Global	≥ 5.0	70–125	0.58	0.83
	≥ 6.0	70–240	0.54	0.76
Spreading zones	≥ 5.1	all depths	0.46	0.55
Western part of the Alpine–Himalayan belt	≥ 4.5	10–30	0.51	0.62
Western active margin of the Pacific	≥ 5.5	65–145	0.50	0.60
North American active margin of the Pacific	≥ 5.1	≥ 8	0.72	no data
	≥ 5.5	≥ 17	0.78	0.83

Therefore, there is a synchronism in manifestations of seismotectonic and climatic processes with rhythms of years and decades. This cannot be explained by mutual relations between these two groups of processes. However, they are possibly correlated with variations of the orbital parameters of the Earth's rotation, geomagnetic field, and solar activity, which can be linked to each other.

9.3. Medium-Period Variations: The 1,200–1,800-yr Cycles

9.3.1. Materials and Methods

Before studying relationships between the development of society and natural events (climatic changes, tectonic movements, earthquakes, volcanic eruptions, and their secondary effects), it is necessary to estimate senses and ways of using the source data. The author limited the analysis (a) by the epoch of producing economy (agriculture and later industry), viz., the Middle and Late Holocene; and (b) by a territory within and around the Alpine–Himalayan orogenic belt, between Greece and Egypt in the west and India and Central Asia in the east (the ancient peoples called it the Eastern Oecumene). This territory is characterized by numerous archeological data and the oldest historical documents, as well as abundant manifestations of seismicity, volcanism, and other geodynamic activity. The climatic changes are clearly manifested there because of general semi-arid conditions. For the comparison, the author represented the results of the similar analysis for the East European Platform.

Databases on human history are full of data on local changes of archaeological cultures, collisions between and within states and cultural communities, etc. In the context of this chapter, it is impossible and useless to analyze all of them. The long-term historical crises (not less than two centuries in typical manifestations) occupying large regions are under our studies. Because we looked for criteria of the crises, which could be find in both developed civilization and primitive community, whose life was reconstructed by small number of archaeological data, the author limited the criteria of crises by signs of three groups of events:

- Signs of social unrest, numerous and strong wars (i.e., destruction of many settlements and towns in the region, reduction of population, manifested by thinning of cultural layers in the settlements, reduction of number of burials);
- Mass migrations;
- Total change of the ethno-political map of the region (i.e., principal changes of boundaries of archaeological cultures and later states, arrival of new communities and states).

On the other hand, archaeological data and historical documents showed that the crises determined breakthroughs in the society and its communities to new technologies and new forms of economical and political relations. The crises alternate the epochs of relative stability and slow evolution of the society. Sedimentological, palynological, and geobotanical data have recorded climatic variations.

Strong earthquakes and variations of their frequency and values of the released seismic energy manifested variations of the geodynamic activity for the particular time interval. The catalog of strong earthquakes ($M_S \geq 5.7$) in the Alpine–Himalayan collision belt (Section

9.2.2) was used to analyze temporal variations of seismicity (Trifonov and Karakhanian, 2004). The recent instrumental techniques give the opportunity to register almost all crustal earthquakes in the Alpine–Himalayan belt with $M_S \geq 5.7$. Registration of strong historical earthquakes (recorded in written manuscripts, publications, or documents) is much less complete, particularly before the 19th century AD. The data on single earlier Holocene earthquakes were obtained by techniques of paleoseismicity and archaeoseismicity. Incompleteness of registration of historical and prehistoric events is evident after a comparison of the earthquake recurrence graphs for different epochs. The graphs are normal for the events of the 19th–20th centuries, but they are deformed for the earlier earthquakes. The latter indicates abnormally large numbers of the strongest earthquakes relative to the weaker ones registered incompletely. It is true not only for events with $M_S = 5.7$–6.9, but for some events with $M_S \geq 7$ as well. The parameters of prehistoric and historical earthquakes before the 19th century cannot be estimated more precisely than ±0.5° for their location and ±0.2 for the magnitude.

Probably, the first description of a strong earthquake can be found in the Book of the prophet Zechariah (The Holy Bible, 1929): '*And his feet shall stand in that day upon the mount of Olives, which is before Jerusalem on the east; and the mount of Olives shall be cleft in the midst thereof toward the east and toward the west, and there shall be a very great valley; and half of the mountain shall remove toward the north, and half of it toward the south. And ye shall flee by the valley of my mountains; for the valley of the mountains shall reach unto Azel; yea, ye shall flee, like as ye fled from before the earthquake in the days of Uzziah king of Judah; and Jehovah my God shall come, and all the holy ones with thee*' (Zec 14:4–5).

As the years of Uzziah's reign are known, the earthquake is dated by ca. 760 BC. Its M_S have been estimated as 7.3 by analogy with the deformation effect of the later seismic events in the area (Nur, 1991). The Khorkhros cuneiform inscription of the Urartu King Argishti I has approximately the same age. It reports about a seismovolcanic event that helped him to subjugate the town of Bekhura. Its ruins were supposedly identified in Armenia to the southeast of the Lake Sevan. Vertical–dextral offset of the fortress wall to about 1.2 m and possible location of the epicenter near the volcano in 5–10 km southward allowed us to estimate $M_S = 7.2$ (Trifonov and Karakhanian, 2004). These two documented seismic events are unique for the region. More frequent registrations of local earthquakes were initiated in the Classical Greece epoch only.

Berberian (1994) analyzed a catalog of historical earthquakes in Iran and paid attention to the possibility of worse registration and preservation of the data on earthquakes in epochs of wars, political instability, and social unrest. To check the importance of this factor, the author compared the number of recorded strong earthquakes in the Aegean, Greece, Anatolia, and the Eastern Mediterranean and stages of political and social rises and falls in the Byzantine Empire. Generally, results obtained did not demonstrate a correlation (Figure 9.9). However, the mid-15th century (the fall of Constantinople in 1453) is marked by a high number of earthquakes; all known earthquakes with $M_S \geq 8$ (in the years 365, 859, 1114, 1201, and 1303) coincide with the epochs of decline or transition from prosperity to decline. This shows not the better registration of earthquakes for the satisfactory epochs, but possible contribution of seismicity to social and political decline.

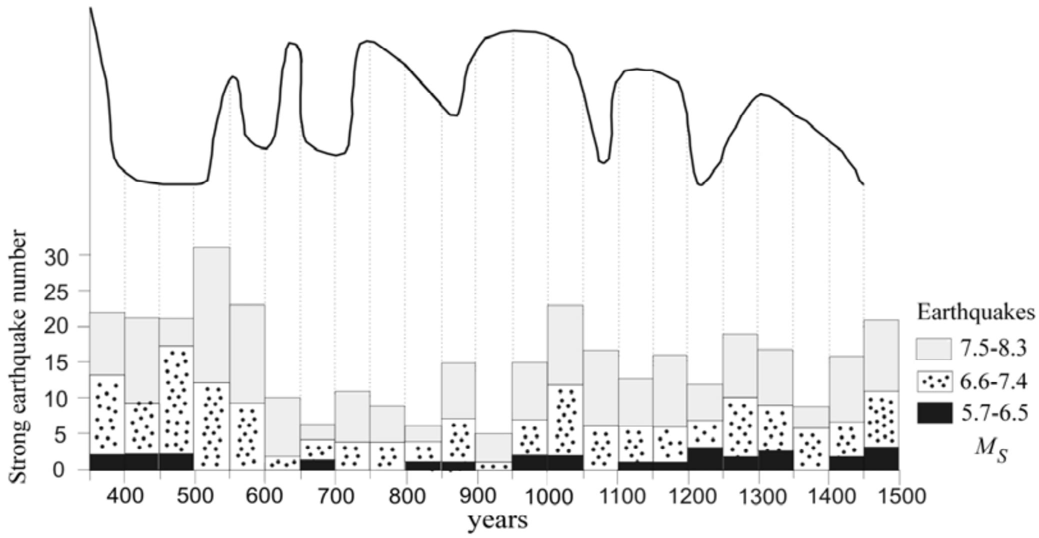

Figure 9.9. Relationships between the number of strong earthquakes in the Crete–Aegean region, Anatolia, and the Eastern Mediterranean and phases of the historical progress (up) and degradation (down) in the Byzantine Empire. Historical changes are shown as an arbitrary curve: progressive periods are curve rises, decline periods are curve decays.

A factor of different completeness of registration is the most appreciable for the analysis of temporal variations of seismicity within local seismic zones. However, its influence smoothes down for the larger territories, thus, the author reduced seismic zones of the central part of the Alpine–Himalayan belt to four seismotectonic provinces (Figure 9.10):

(I) The region of interaction of the African and Anatolian Plates and the European part of the Eurasian Plate: the Carpathian–Balkan (1) and Crete–Aegean (2) regions, Eastern Mediterranean (3), and the western Anatolia (4);

(II) The western flank and the northern front of the Arabian Plate and the region of its interaction with the Eurasian Plate: the Levant and East Anatolian zones (5), the eastern part of the North Anatolian zone, the Lesser Caucasus (6) and the Great Caucasus (7);

(III) The northeastern part of the region of interaction of the Arabian and Eurasian Plates: the Zagros (8), Alborz and Allah Dagh (9), Makran and the central-eastern Iran (10), Binalud and Kopet Dagh (11);

(IV) The western flank and the northern front of the region of interaction of the Indian and Eurasian Plates: the Indus basin and Beluchistan (12), the western Himalayas, Karakorum, Hindu Kush, Pamirs, the western Kun Lun and the adjacent parts of Tibet and Tarim (13), the western Tien Shan, the Afghan–Tajik basin and the adjacent part of the Turanian Plate (14), the southern (15) and northern (16) Tien Shan.

Histograms of values of seismic energy, released in the provinces I–IV and in the entire central part of the Alpine–Himalayan belt, are represented in Figure 9.11.

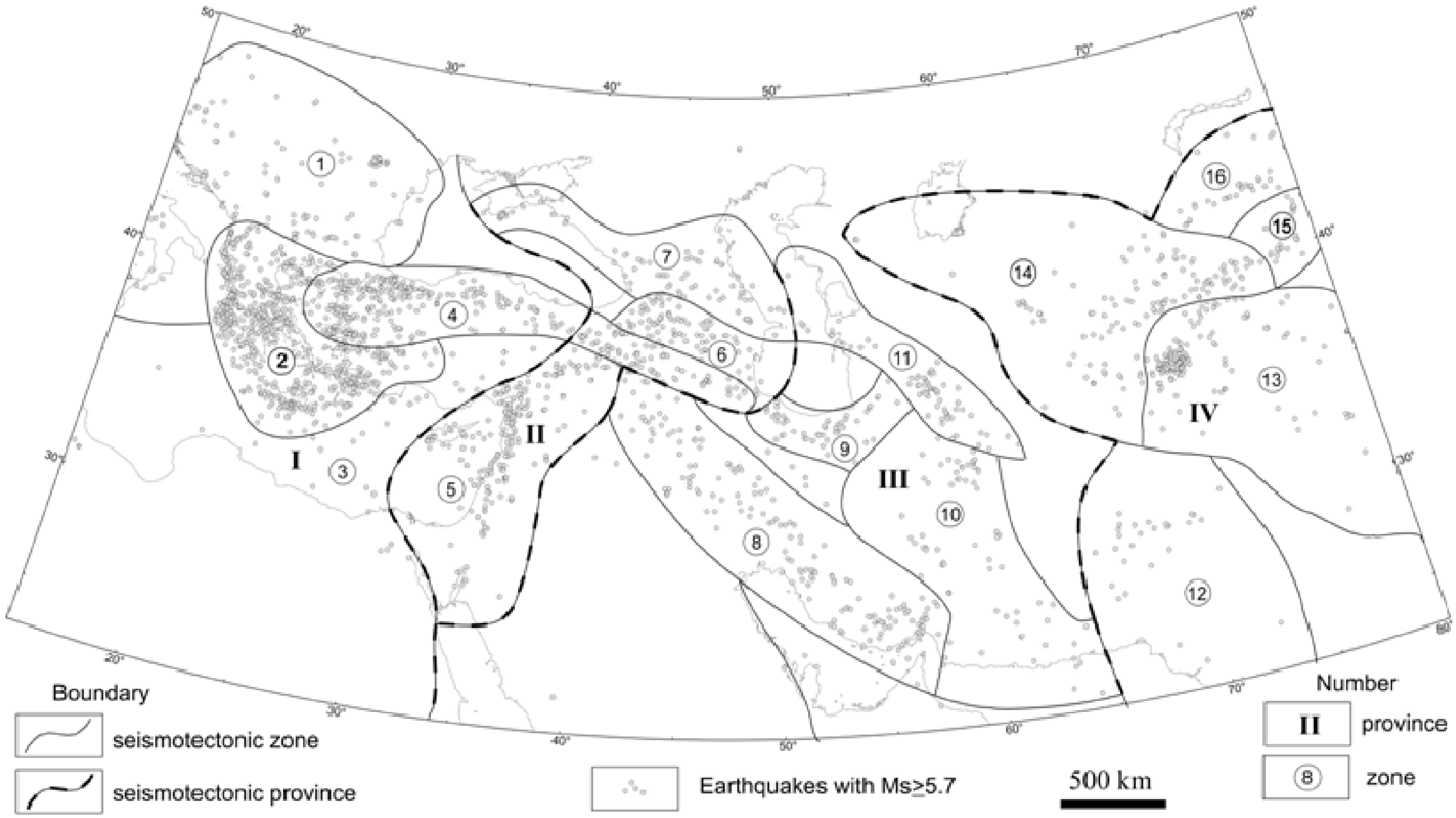

Figure 9.10. Epicenters of strong ($M_S \geq 5.7$) earthquakes, seismotectonic zones and provinces in the central segments of the Alpine-Himalayan collision belt (Senko et al., 2004).

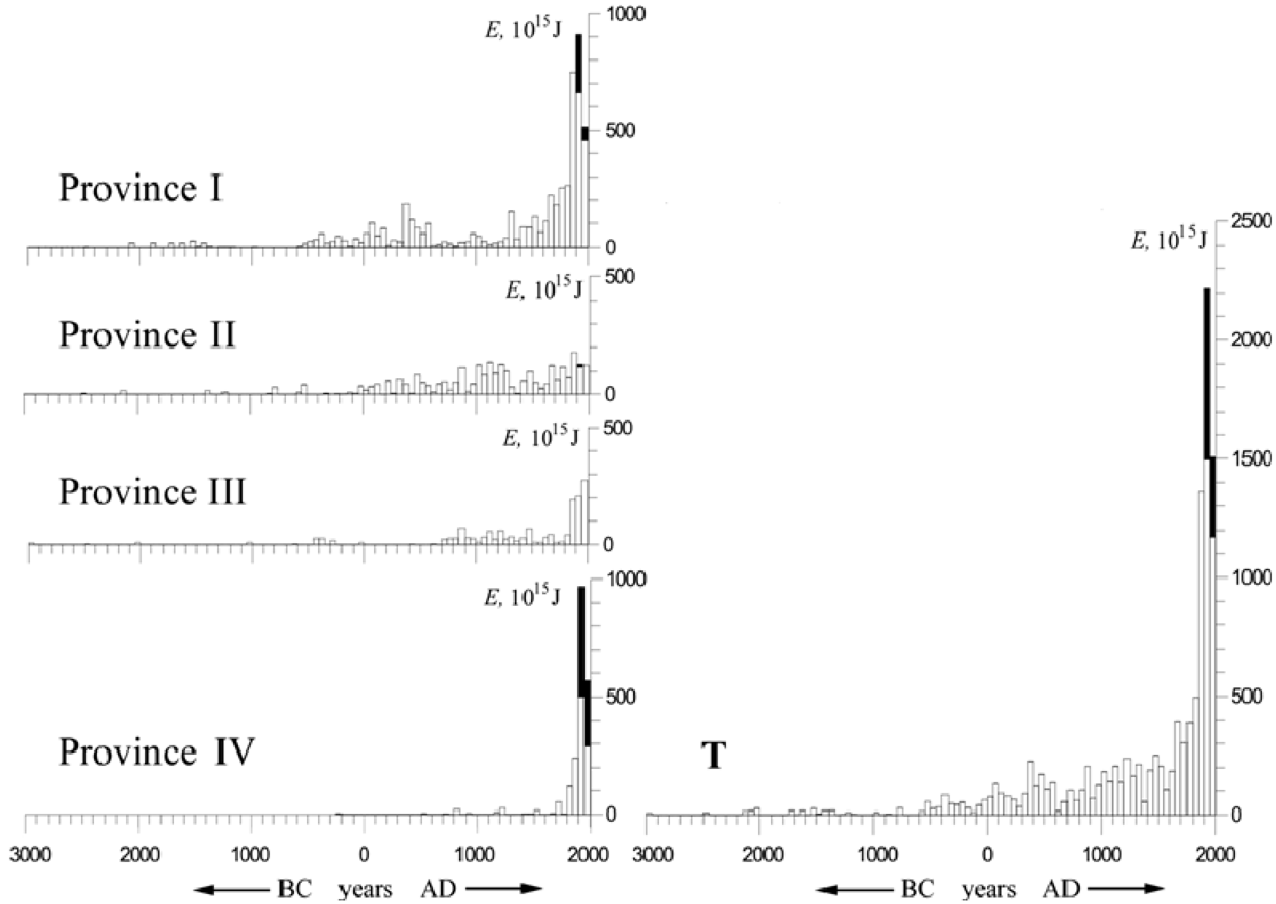

Figure 9.11. The seismic energy E released by earthquakes with $M_S \geq 5.7$ in the seismotectonic provinces I–IV and the entire central segments of the Alpine–Himalayan collision belt (T) (Senko et al., 2004). The histograms were plotted with the 50-yr step. The energy released by earthquakes with intermediate hypocenters (deeper than 70 km) is shown by black color.

To analyze the temporal variations of seismicity in the provinces and in the belt as a whole, it is necessary to consider the following: Until the mid-1st millenium BC, earthquakes were recorded very incompletely by archaeoseismological and paleoseismological means only. The author introduces the term "a stable registration" for the historical seismicity. For the studied seismic zone or province, the stable registration means presence of data about two or more earthquakes for a half-century and absence of the registration gaps for the further 50-yr intervals. The stable registration started in the Aegean region in the second half of the 6th century BC, and in the North Anatolian zone and the Eastern Mediterranean in the second half of the 4th century BC. In the Great Caucasus, it began in the mid-5th century AD, and in the Lesser Caucasus – in the early 8th century. Blossom of the Baghdad Caliphate with its high level of sciences was favorable for the stable registration of seismicity in the Middle East and Central Asia. It began in Zagros and the northern Iran in the 9th century, and in Egypt, the central and eastern Iran, and Central Asia (Bactria and Sogdiana) in the 10th century. The stable registration started in the Christian Carpathian–Balkan in the 12th century. However, in India and the mountains of Central Asia, it began only after the arrival of the English and Russian, respectively, colonial administrations in the mid-19th century. The registration became much more complete in the 19th century and the instrumental technique improved principally the registration in the 20th century.

These considerations give some keys to interpret the histograms of temporal variations of seismicity (Figure 9.11). For example, the peak of seismicity in the 10th–14th centuries AD corresponded to the smaller seismic activity than the peak of the 4th–8th centuries AD because of the essential increase in areas of the stable registration. The peak of the second half of the 17th century was probably no less than the peak of the second half of the 19th – the first half of the 20th centuries because the latter depends partly on the progress in registration.

9.3.2. Historical Crises in the Oecumene

In total, the history of Eastern Oecumene during the last six millennia (the Middle and Late Holocene) was characterized by five crises manifested in social unrest, mass migrations, and political changes (Table 9.2). On the other hand, the crises determined breakthroughs to new technologies and novel forms of economical and political relations.

The *first crisis* is hypothetical. Probably, just this crisis caused preconditions for formation of the first Sumerian towns-states as well as the complex agricultural communities in the northwestern Black Sea and Balkans regions (the Cucuteni–Tripolie and similar cultures) and in the Transcaucasus (the Kura–Arax culture – Figure 9.12) in the first half of the 4th millennium BC. The first attempts to use bronze took place and the jigger wheel was created. In the Peruvian coast of the Pacific, the cultures arrived, which combined agriculture and sea trades. Complication of the primeval communities of different levels of social development was observed in the northern Chile, Eastern China, and Japan after ca. 3800 BC.

Not so mush data exists about the *second crisis* of the mid-3rd millennium BC. Confrontation of the oldest Sumerian towns-states increased in that time and finished with the collapse of the Ancient Sumer and the rise of Akkad. In Egypt, starvation took place in the 24th–22nd centuries BC and mortality increased to almost 10 times (Selivanov, 2000). Finally, it led to the collapse of the Old Kingdom.

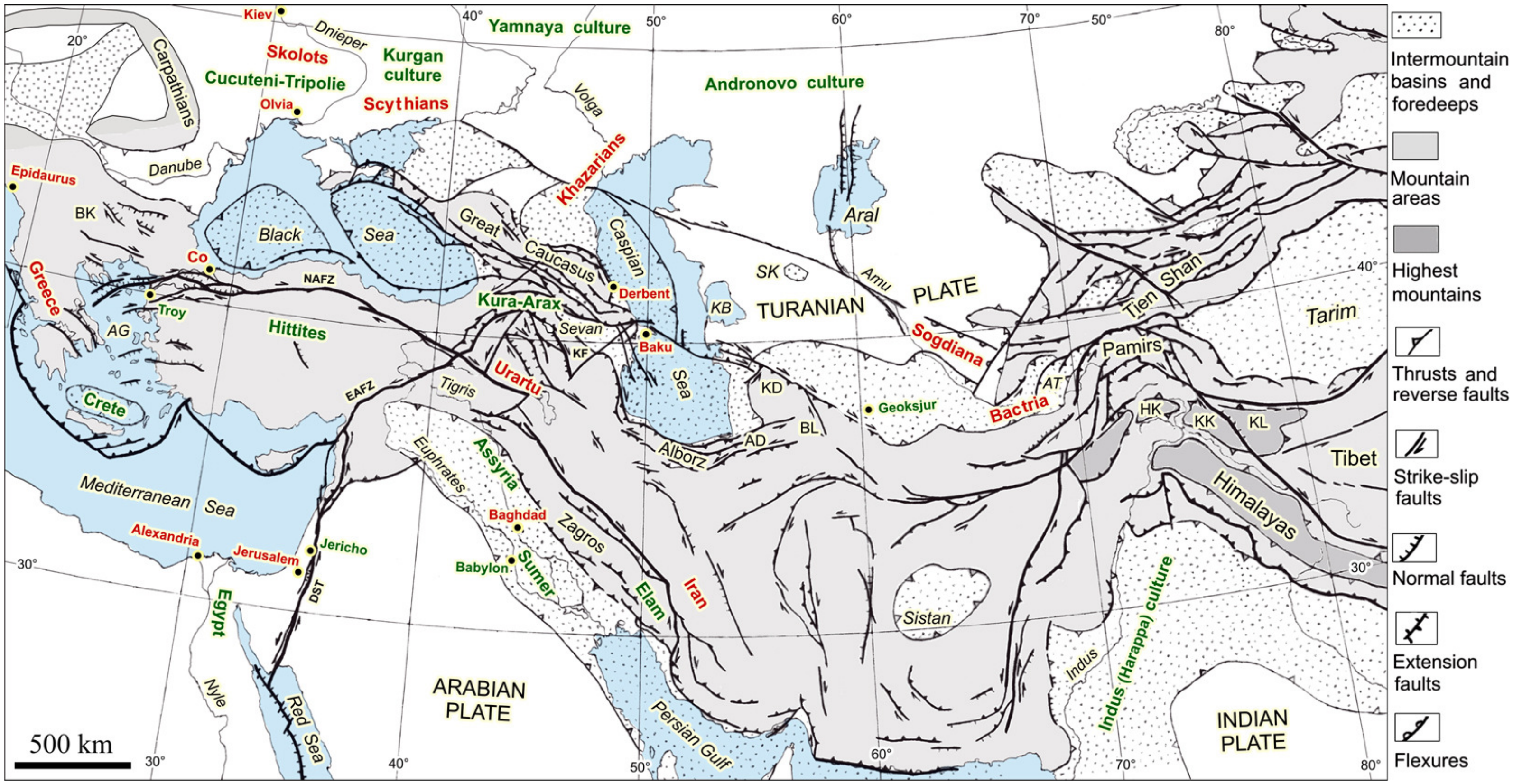

Figure 9.12. Main Quaternary tectonic features, archaeological cultures, historical units, and sites in the central segments of the Alpine–Himalayan collision belt and the adjacent part of the Eurasian Plate. Green are the Chalcolithic and Bronze Age cultures, tribes, countries, and towns; red are the Ancient and Medieval countries, tribes, and towns. Thick lines are the largest Quaternary faults. AD – the Allah Dagh Range, AG – the Aegean Sea, AT – the Afghan-Tajik basin, BK – the Balkans, BL – Binalud Range, Co – the city of Constantinople, DST – the Dead Sea Transform, EAFZ – the East Anatolian fault zone, HK – the Hindu Kush Mountains, KB – the Gulf of Kara-Bogaz-Gol, KD – Kopet Dagh, Kf – the Khanarassar fault, KK – the Karakorum Mountains, KL – the Kun Lun Mountains, NAFZ – the North Anatolian fault zone, SK – the Sarykamysh basin.

Table 9.2. Multi-century crises of the Middle and Late Holocene

Time	Climate	Tectonics	History
The early 4th millennium BC	Arrival of the annual variations in the Oecumene. Start of the El Niño regime in the Pacific.	Strong earthquakes and volcanism in Armenia. Strong earthquakes in the Zagros.	First signs of using bronze. First towns-states in Sumer. Origination and development of the producing economics in the Pacific.
The mid-3rd millennium BC	Aridization in Egypt, Sumer, Near East, the southern Turkmenistan, and the Sevan region.	Strong earthquakes and volcanism in Armenia and Southern Syria.	Decline of early agricultural communities. Transition to the semi-nomadic cattle breeding. Collapse of the Sumer and the Old Egyptian Kingdom.
The second half of the 2nd millennium BC	Aridization in China, Indus Valley, Central Asia, Turkmenistan, Turkey, Transcaucasus, and the Persian Gulf.	Numerous strong earthquakes.	Collapse of the Achaean states, Hittite Kingdom, Babylon, and Indus civilization. Migrations of the "Peoples of Sea" and Arameans. Transition to the Iron Age.
The mid- and early second half of the 1st millennium AD	Aridization in Central Asia, Afghanistan, Indus Valley, the Great and Lesser Caucasus, Israel, and North Africa.	Two peaks of seismicity: in the 4th and 6th–7th centuries. Activity lasted up to the 9th century.	Collapse of the Western Roman Empire and the Sassanian Iran. Arabic conquests. Mass migrations and foundation of new states. Formation of the Southern Slavic branch and the first Slavic states.
The 17th–20th centuries	The Little Ice Age: cooling and advance of mountain glaciers. Aridization in Central Asia.	Two peaks of seismicity: in the second half of the 17th century and in the late 19th – early 20th centuries.	Reduction of agriculture and starvation in Europe and Russia. Mass migrations. Industrial revolution. The World Wars in the first half of the 20th century. New social-economic concepts.

Reduction of the Early Bronze proto-town settlements occurred in the late 3rd millennium BC in all of Palestine (Marchetti and Nigro, 1998). The same tendency took place in the Balkan–North Black Sea region, where the Cucuteni–Tripolie culture fell into decline: huge and well-designed super-centers transformed into small settlements and finally the cultural system collapsed (Masson, 1999). At the same time, the Geoksjur Oasis (Figure 9.12) perished in Central Asia. Many settlements of the Kura–Arax culture also perished after the mid-3rd millennium; the new settlements concentrated along the largest and deepest rivers or founded in hills and low mountains. A part of the population migrated to the southeast (northwestern Iran) and to the southwest (eastern Turkey and Palestine). The new settlements built in the difficult-to-access sites that demonstrated an increasing threat from the cattle-breeding tribes, immigrated to the traditional Kura–Arax territory. Finally, the Kura–Arax cultural community disintegrated and collapsed in the late 3rd millennium BC (Trifonov and Karakhanian, 2004).

However, in southeastern Europe and southwestern Asia, the second crisis and associate migration of peoples led to the transition from the earlier complex agricultural communities to the cultures of semi-nomadic cattle-breeders using horse for transportation. New features characterized these cultures: social stratification and separation of the military-aristocratic elite (Masson, 1999).

The *third crisis* is known better. It was connected with the transition from the Bronze Age to the Iron Age. The crisis was marked by complex political events. In the 14th century BC, the political dominant of the Oecumene was the rivalry of Egypt and Hittite Kingdom (Figure 9.12). After long wars, exhausting both states, they concluded the peace treaty in ca. 1284 BC (Zabłocka, 1982). Probably, the resources of Egypt were larger that demonstrated the great construction carried out by Ramesses II after concluding the treaty. After a brief rise in the first half of the 13th century BC, Assyria was weakened by the permanent rivalry with Babylon for hegemony in Mesopotamia and both these states were not powerful in the end of the century (Zabłocka, 1982). After the Achaean towns-states had won their former suzerain, the Minoan Crete, in ca. 1450 BC, they dominated in the Aegean region (Andreev, 1989).

However, the situation changed in the late 13th century BC. The Achaean towns were destroyed and occupied by the invasion of the Dorian and Thracian–Illyrian tribes (Andreev, 1989). This collapsed the Crete–Mycenaean civilization and provoked the mass emigration of the former population, drawing other tribes into the movement. This exodus was perceived in the Near East as invasion of "the Peoples of Sea". In the treaty between Ramesses II and the Hittite King Hattusilis III, they are called as paid independent allies of the Hittite king (Zabłocka, 1982). However, the tone of the information changed later. In ca. 1234 BC, the text of Pharaoh Merneptah reported about '*the northern peoples from all countries of the World*', which joined with Libyan tribes and began to pass the Egyptian boundary. These peoples were Akaivasha (Achaeans), Turusha (Etruscans), Shekelesh (Sicelians), Lukka (Lycians), and others. The later (after 1215 BC) notice of Ramesses III in the temple Medinet-Habu at Thebes reported about the invasion of strange peoples: '*Hatti* (Hittite Kingdom), *Kode, Carchemish, and Arzawa, Alashiya* (small states in Syria) *collapsed simultaneously. Warriors moved to Egypt and wave of fire moved before them. They were Peleset* (Pelasgians, which were called by Philistines in their new land and give its name to Palestine), *Tjeker, Shekelesh, Danuna* (Danaeans? – total name of Achaean–Ionian tribes of Greece) *and Vashasha*' (Zabłocka, 1982).

Because of the invasion, the Hittite Kingdom collapsed in ca. 1200 BC, and the former inhabitants and the newcomers founded small Late Hittite states in its territory. After losing this suzerain, Troy (Wilusa of the Hittites) fell in ca. 1180 BC (Korfmann, 2005). Probably, just this event became the historical base for the famous Homer's poems (Homer, 1996). Newcomers founded new states in Syria and Palestine, where Egypt lost its influence. Because of the difficult victory of Ramesses III in 1190 BC, Egypt held out, but had to permit settling of the newcomers in the Nile Delta.

The Mesopotamian inhabitants underwent the invasion of the Western Semitic nomadic tribes of Aramean from Arabia. The first notices about conflicts with them were dated by the 14th century BC. Until the late 12th century BC, Assyria parried their impact. The Arameans limited themselves by robbery attacks only and did not try to occupy the agricultural territories. However, in the early 11th century BC, the Arameans captured the Middle Euphrates and deprived Assyria of rich agricultural areas and way to Syria. Because of starvation and political instability, Assyria and Babylon could not organize a serious defense. The territory of Assyria was reduced and the Aramean tribe of Chaldeans captured Babylon. The Arameans occupied a part of the Late Hittite states and formed new states in Syria, where they shifted to the settled life. Migration of the Aramean tribes initiated movement of the Jewish nomads. They moved to Palestine, where they mixed with the earlier Jewish population (the people of Moses; Pharaoh Merneptah reported crushing Israel in the late 13th century BC) and relative tribes as well as the Canaanites and shifted to the settled life. Consolidation of the society, caused by a struggle with the adjacent Arameans and Philistines, led to the formation of the Israel state in ca. 1000 BC (Zabłocka, 1982).

A mass migration involved the Arian tribes, which lived a semi-nomadic life in the South Ural region and western Central Asia. The first wave of the Indo-Aryans arrived in Iran in the mid-2nd millennium BC (Frye, 1963). Later they migrated to northwestern India, where they settled in the ruins of the Indus Valley agricultural civilization, which had been formed by Dravidian tribes, relative to the Elam people (Figure 9.12). The first signs of trouble arrived in the first half of the 2nd millennium and degradation became evident in the middle of the millennium. Only several relics of the civilization remained in the oceanic coast and northwestern Hindustan. The Irano-Aryans came to Iran in the late 2nd millennium BC and took control of the mineral resources necessary for the Mesopotamian states. This strengthened Elam controlled trade relations between Mesopotamia and the eastern countries.

The historians explain these changes of political situation in the Eastern Oecumene by inner social and economic difficulties in the civilized societies of Eastern Mediterranean and Near East. The difficulties were caused by extensive agriculture, permanent wars, impoverishment of known mineral resources, and the complication of assimilating the new resources controlled by martial tribes (Zabłocka, 1982). Although the majority of these factors had acted before the crisis, they gave the results only for the crisis. Obviously, there were some additional factors.

Historical collisions of the fourth and fifth crises are well known and are briefly described. The *fourth crisis* continued from the 4th to the 8th centuries AD. It was the collapse of the Ancient World and transition to the Medieval feudalism. The crisis was marked by the Migration Period and changes in the political map of the Oecumene. At that time, the flourishing classic kingdoms of India degraded and collapsed. The fall of the Western Roman Empire was a very important event, which influenced the European history and cultural development for the next several centuries. The fall was accompanied by the formation of small temporary states in Europe, the foundation of two new cultural centers, Byzantine and Arabian Caliphate, and the spreading of Christianity and Islam, which became the world's religions. Quickness strikes were typical for the collapse of both the secular institutions of the Roman Empire and occupation of huge and partly densely populated civilized territories by relatively small tribes of the Arabic nomads. Each of these events lasted only ca. 100 yr. It is written a lot about historical preconditions of the both events. The decline of the Roman society, degradation of the ruling institutions, devaluation of the former culture and ethic principles by dissemination of the Christian ideology, and the economic exhaustion by the permanent struggle with "barbarians" are evident (Gibbon, 2003). The political and economic weakness of the Sassanian Iran is also doubtless. Its last rulers lost the control of the remote provinces (Frye, 1963). Nevertheless, only social-economic factors cannot explain all historical peculiarities of the crisis epoch.

The epoch, starting in the 17th century and continuing up to the early 20th century, can be interpreted as the *fifth crisis*. It was the crisis of feudalism. The crisis led to the formation of a new social-economic system founded on a free market, democratic society, and quick development of industrial technologies. The crisis was manifested by the formation and collapse of the world colonial system. It was accompanied by the mass migration (mostly to America) and the formation of new world centers of political influence. The 20th century was characterized by the two World Wars, formation and collapse of the totalitarian regimes, and attempts to create a socialistic society. On the other hand, the last crisis coincided with globalization of economy caused by the world expansion of the North American–West European civilization, as well as exacerbation of the general ecological crisis caused by increasing pressure of the society on nature. The last process has strengthened from the 19th century and has threatened the existence of the humanity. The globalization and the world environmental crisis have masked features of the fifth historical crisis.

Therefore, the history of the Eastern Oecumene in the Middle and Late Holocene was characterized by five crises (Table 9.2). Each of them lasted for about three centuries, whereas their social and political consequences could be felt even 100–150 years later. The crises repeated once in ~1,200 yr, whereas intervals between analogous phases of the third and forth crises comprises ~1,800 yr. According to Gumilev (1990), the ~1,200-yr period is typical for the active development of any ethnos.

9.3.3. Relationships between Historical Development and Climatic and Tectonic Rhythms in the Oecumene

The *first crisis* epoch corresponded with the transition from the early stage of the Atlantic period to its late stage. The Early Atlantic was characterized by the warmest (for the Holocene) conditions and the heightened humidity in the midlatitudes of the continents. In the final part of that stage, the last essential rise of the oceanic level took place. This could be associated with the catastrophic collapse of glaciers in the West Antarctic (Hughes, 1987). Big storms and high floods accompanied the sea-level rise. The strongest flood in southern Mesopotamia would remain in the people's memory as the Deluge (Trifonov and Karakhanian, 2008).

The Late Atlantic climate was more changeable with the heightened humidity but the lower average temperature in the midlatitudes. The danger of floods was reduced in southern Mesopotamia. It gave a possibility for the development of stable settlements of the town type and irrigation system that became the base for formation of the Sumerian civilization. The start of the climatic variations was also found in the Pacific coasts as the El Niño (Southern Oscillation) regime, which produced the periodic (every 3–7 yr) penetration of the cold oceanic waters to the tropical latitudes (Sandweiss et al., 1999). This caused fluctuations in both bioproductivity in the offshore waters and the climatic conditions in the coasts (Section 10.5.3) that influenced formation or development of the producing economics of a part of the coastal population.

At that time, the seismotectonic and volcanic activity occurred in the southeast of the Lake Sevan in the Khanarassar fault zone. The Porak Volcano eruption took place there in the late 5th – early 4th millennium BC. This coincided with (or, probably, was preceded by) a strong earthquake (Trifonov and Karakhanian, 2004). One or two of the same events happened southeastward, in the Syunik pull-apart structure of the Khanarassar zone in the first half of the 4th millennium BC (Karakhanian et al., 1997). These seismotectonic and volcanic events produced fires in the area and coincided with a temporal aridization and some cooling in the Sevan region resulted in a regression of the lake (Sayadian, 1985) (Figure 9.13). The strong earthquakes happened in the early 4th millennium BC in the Central Zagros.

The *second crisis* coincided with the cooling and aridization that took place in the midlatitudes of the Northern hemisphere in the mid-3rd millennium BC after the Atlantic Optimum. The aridization of the 24th–22nd centuries BC was manifested in Egypt by a sharp fall of the annual Nile freshets that influenced immediately the productivity of agriculture. However, at the end of the millennium, the normal situation was restored and even stronger floods took place during the Pharaoh Amenhotep III reign (Selivanov, 2000). The aridization was more perceptible in the boundaries between deserts and areas of the irrigated agriculture. Probably, just the aridization caused the baneful conflicts between the Sumerian towns-states for control of the water sources of irrigation. The aridization took place in Palestine and adjacent territories in ca. 2300 BC (Nissenbaum, 1994). In southern Turkmenistan, the aridization was manifested by lateral relocation and degradation of the Tedjen River that caused destruction of the Geoksjur Oasis. In the Sevan region the crisis coincided with aridization and the maximum regression of the lake (Sayadian, 1985). The aridization could cause migration of the nomadic tribes from the drought-affected steppes to the agricultural oases that resulted in wars and the destruction of the agricultural communities.

The volcanic activity of the second crisis epoch occurred in southern Syria and the volcanic center of Ararat, where the volcanic products covered settlements and constructions in the middle and early second half of the 3rd millenium BC (Trifonov and Karakhanian, 2008). The signs of strong earthquakes were found in the Central Zagros (Bachmanov et al., 2004) and Pambak–Sevan fault zone in Armenia, where two earthquakes with magnitudes $M_S \geq 7.3$ and $M_S \geq 7.2$ destroyed the Kura–Arax settlement of the 26th–22nd centuries BC (Philip et al., 2001).

One of the sources of the *third crisis* could be climate deterioration (Figure 9.13). In the Indus Valley, the period of 3000−1800 BC was warm and humid that favored the prosperity of the Indus civilization. However, the climate became increasingly arid in the period of 1800−1000 BC. This led to the degradation and fall of the civilization (Dhavalikar, 1991).

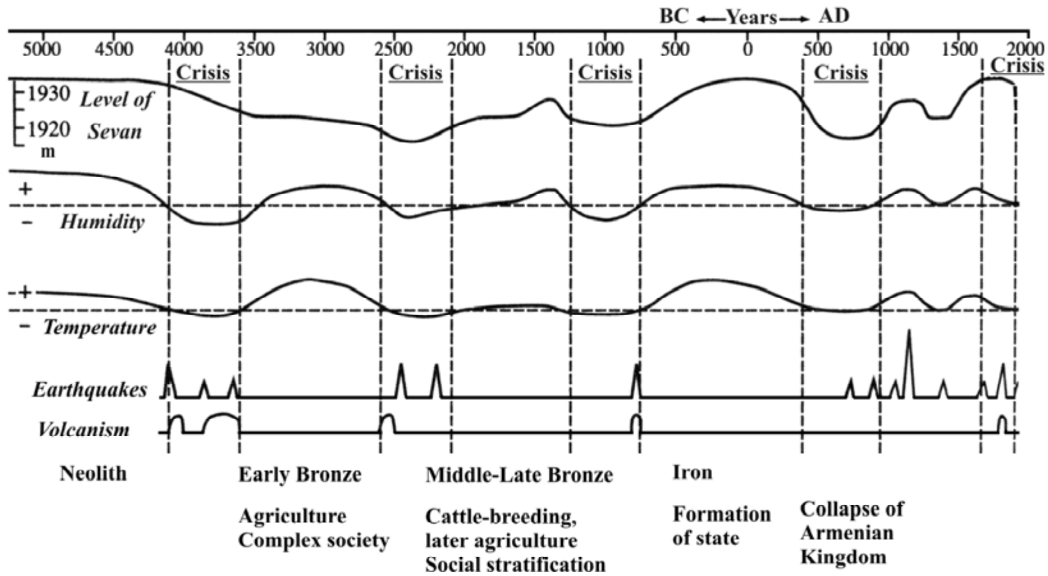

Figure 9.13. Relationships between the climatic, volcanic, seismotectonic, and cultural events in the Lake Sevan region (Trifonov and Karakhanian, 2004). Deviations in air temperature and humidity regimes as well as seismic and volcanic activities are shown as arbitrary curves.

The aridization took place within the large territory. It was recorded in the northwest of the Indian shield by regression and drying out of the Lake Didvana (Murzaeva, 1991). In the mountains of Central Asia, the former warm and humid conditions changed by cooling and aridization in the mid-2nd millennium BC. These were accompanied by a glacier advance in the Himalayas in ca. 1000 BC (Bhattacharyya and Yadav, 1991).

The aridization occurred in China (Liu, 1997). In the plains of Central Asia, the aridization coincided with the northward relocation of the Amu Darya River channel toward the Aral Sea and, hence, drying of the Lake Sarykamysh and Uzboi Channel lasted from the early 2nd millennium BC (Velichko, 1993). The aridization increased in the 8th–7th centuries BC when the regression began in the Aral also. The humid Atlantic conditions lasted in the southern Turkmenistan until the late 3rd millennium BC. Later, the aridization progressed; it was accompanied by degradation of forests (Trubikhin, 1989; Murzaeva, 1991). The aridization of steppes in Kazakhstan and Central Asia was one of the causes of migration of the Aryan nomads to Iran and later to India.

The aridization was registered by palynological data in central and northern Turkey (Bottema, 1991) and in the Persian Gulf region (Murzaeva, 1991). It continued in the Lesser Caucasus (the Sevan region) up to the 9th century BC (Figure 9.13). Perhaps, just the aridization in the Arabian steppes was one of the causes forcing the Aramean nomads, which had limited themselves before by the plundering raids on the agricultural oases, to begin their occupation. On the other hand, the aridization weakened the economics of the agricultural communities and made them easier prey for the invaders. In 1500–800 BC, only Palestine was characterized by relative humidification with maximum moistening in the 13th century BC (Figure 9.14) (Issar, 1996; Issar and Zohar, 2007). This caused the immigration of the Jews, Arameans, and Philisians.

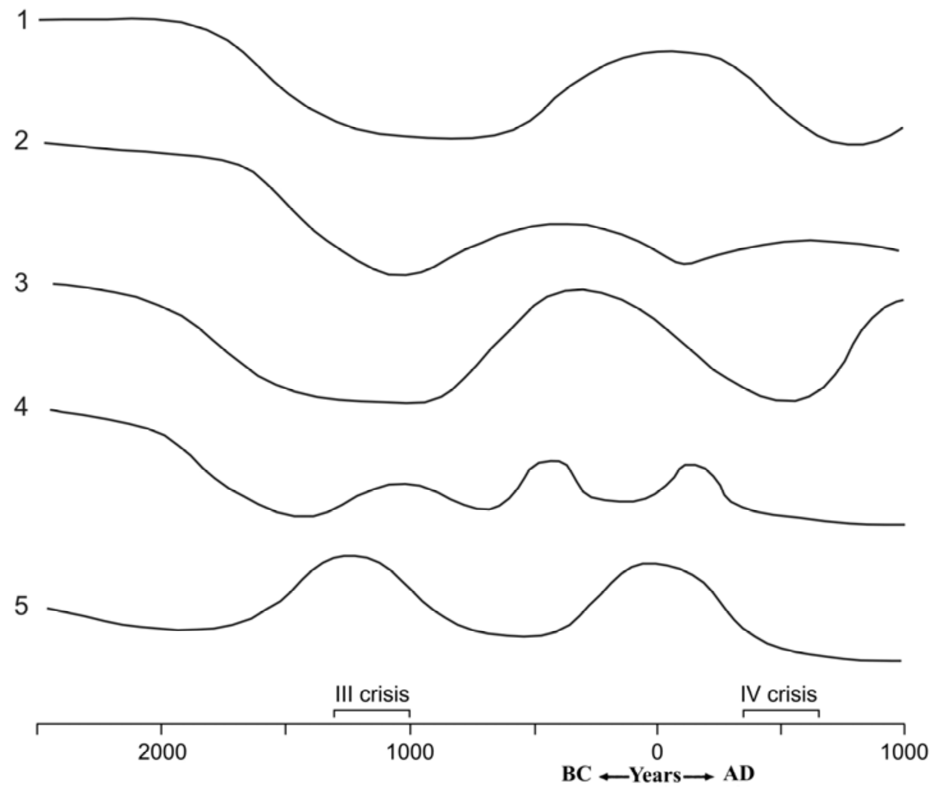

Figure 9.14. Climatic changes in the Eastern Oecumene from the 2nd millenium BC to the 1st millenium AD: 1 – the Indus Valley (Dhavalikar, 1991), 2 – the Himalayas and the Central Asia mountains (Murzaeva, 1991; Velichko, 1993), 3 – the Aral–Sarykamysh region (Velichko, 1993), 4 –southern Turkmenistan (Trubikhin, 1989; Murzaeva, 1991), 5 – Israel (Issar, 1996). Arbitrary curves represent humidification (rise) and aridization (decay).

As discussed in Section 9.3.2, the Egyptian list of "the Peoples of Sea" contains mainly the peoples of the Aegean region, including Crete and Sicily: Danaeans, Achaeans, Pelasgians, and Sicelians. The Aegean region is marked by the high seismicity. The archaeoseismological data showed that the main Achaean towns were destroyed in the 13th century BC by strong earthquakes (Stiros and Jones, 1996) that made easier their conquest by the Dorian and Thracian–Illyrian tribes. One or two strong earthquakes took place in Troy (the northwestern Minor Asia). The first one damaged and deformed the constructions of Troy-VI (Figure 9.15). These constructions continued to serve for the Troy-VI i epoch, which was identified with Homer's Troy captured by the Achaeans (Homer, 1996). Therefore, it is not clear, whether the first earthquake happened before the Troy-VI i epoch, as Korfmann (2005) considered, or if it occurred just during the Trojan War that helped the Achaeans to win. According to Selivanov (2000), degradation of the Indus civilization, the most evident in the second half of the 2nd millennium, could be caused not only by the social-economic and climatic factors, but by seismic destruction of the irrigation system as well. As the late echo of this epoch of seismotectonic activity, we interpreted the earthquakes in Israel and Armenia in the first half of the 8th century BC. The Armenian earthquake was accompanied by volcanic eruptions, which helped Urartu to subjugate the local tribes in the southeastern Sevan region (the Khorkhor inscription of Argishti I) (Trifonov and Karakhanian, 2004).

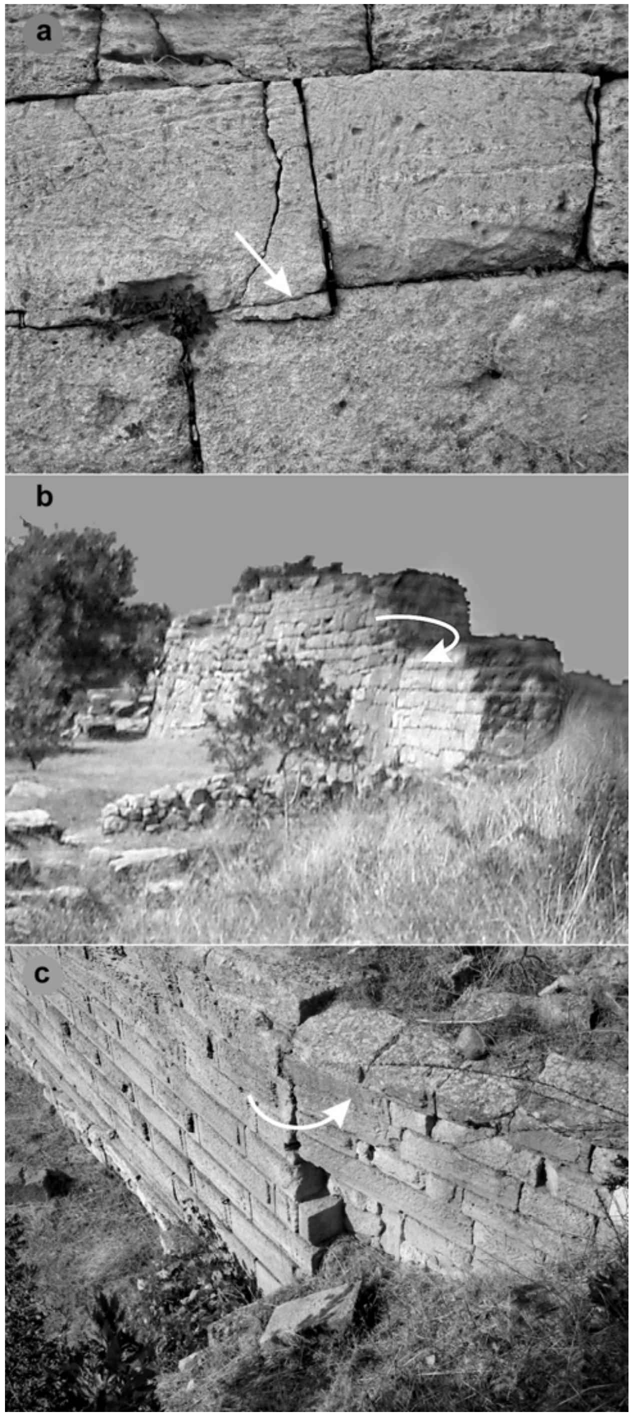

Figure 9.15. Seismic destructions in Troy: (a) break of anti-seismic constructions in the eastern part of the Troy VI walls; (b) the clockwise rotation of the wall of the Palace VI M (southern part of the Troy VI); (c) the counter-clockwise rotation of the wall of the Roman epoch (southwestern part of the Troy IX). The contrary seismic rotation of the adjacent constructions of the Troy VI and IX proves that these deformations were produced by different earthquakes.

The aridization took place in the *fourth crisis* epoch (Figure 9.14). In Central Asia, the aridization was outlined in the 3rd century AD and lasted until the 11th century. Its indicators were regression of the Lake Sarykamysh and stopping on the Uzboi runoff (Velichko, 1993). The progressing aridization began in the southern Turkmenistan in the late 3rd century (Trubikhin, 1989). In the Indus Valley, the aridization replaced the relatively humid conditions, which had taken place up to the 5th century (Dhavalikar, 1991). The aridization took place in the Sistan basin (the southwestern Afghanistan) and the Sevan region after the humid epoch of the 1st–2nd centuries AD (Murzaeva, 1991). In the Sevan region, the aridization continued from the 5th to 10th centuries; it was accompanied by regression of the lake (Figure 9.13). At the same period, the aridization took place in the northwestern Caucasus and the Great Caucasus glaciers shortened. In Israel, the aridization replaced the relatively humid period of the last centuries BC – the first centuries AD, when the Dead Sea level had been 50 m higher than now and its coast had been near Jericho (Issar, 1996; Issar and Zohar, 2007).

The aridization was pernicious for the Roman Empire. The growth of the population of the city of Rome, which reached 1.5–2 million in the flourishing stage, transformed the agricultural geography of the Empire. Inhabitants of the Apennine Peninsula specialized in cattle-breeding, vegetable-growing, gardening, and production of vines, whereas production of corn and vegetable oil (the main food products) was concentrated in Northern Africa, Syria, and Palestine. The aridization of these regions worsened the complicated problem of supply of the metropolis by food products and precipitated the collapse of the Empire. The aridization reduced the agricultural production in the near-desert provinces of the Sassanian Iran, including Mesopotamia and Central Asia. This complicated the social-political situation and made them easier prey for the Arabians.

In the background there was an increase in the released seismic energy during the second half of the 1st millennium BC and the 1st millennium AD, caused by the beginning of earthquake registration, the epoch of the fourth crisis showed the rise known as the Byzantine tectonic paroxysm. It began in the 4th century AD, when the strongest 365 AD Crete earthquake took place ($M_S = 8.3$). Because of the earthquake, the southwestern and western margins of Crete were uplifted up to 8.5 m (Pirazzoli, 1986), whereas the eastern part of the island was locally subsided down to several meters (Chernov, 2004). This event provoked probably the strong earthquakes in the Adriatic Sea (the city of the Illyrian Epidaurus – Figure 9.12) and in the southern coast of the Mediterranean (the city of Alexandria) and these cities were partly subsided. The strong earthquakes occurred in the 5th–7th centuries in the Aegean region, in western part of the North Anatolian fault zone, and Eastern Mediterranean (Figure 9.11). Two peaks of seismicity can be differentiated within the Byzantine tectonic paroxysm: in the 4th and 6th–7th centuries. Probably, the seismic events in the Levant (Dead Sea Transform) and East Anatolian zones outstripped the events in the North Anatolian zone to several decades (Trifonov and Karakhanian, 2004). In the 8th–9th centuries, the strong earthquakes took place not only in those regions, but in the Armenian Highland, Zagros, northern Iran, and Bactria as well.

The *fifth crisis* was also characterized by climatic deterioration known as the Little Ice Age (Grove, 1988). Its first signs arrived in the late 16th century. The cooling reached maximum in the 17th century and continued until the 19th century. The cooling occurred in different parts of the Northern hemisphere, from North America to China. Advance of glaciers was registered in Alaska, Scandinavia, Iceland, the Andes, Alps, Caucasus, Taurus, and other mountains of the Alpine–Himalayan orogenic belt in the 16th–19th centuries. The advance was accompanied by aridization in Central Asia, Tibet, and the Inner Himalayas as well as small humidification in the northwestern Caucasus and Sevan region. The cooling decreased productivity of agriculture and forced peoples to change traditional agricultural practices in some regions. The starvation, caused by high cooling in Britain in the late 17th century, brought bigger losses than the plague epidemic in the 1340s (Selivanov, 2000).

The weak warming with episodes of cooling took place in the 18th–19th centuries. In the 20th century, the warming became more significant: the average near-ground temperature increased to almost 1° C for the century and rose to about 0.75° C more for the last 10–15 years (Losev, 2001). The warming-up has been observed at the global scale, particularly in the Northern hemisphere, but the picture is more variable at the local level. Many scientists explain the warming by an increase of the greenhouse effect because of the rise of the CO_2 concentration in the atmosphere. They explain this rise by the Industrial Revolution and population growth or by indirect results of human activity, such as destruction of the natural ecosystems controlling CO_2 concentration and the water vapor in the atmosphere. However, Kondratiev and Donchenko (1999) showed that no real evidence exists to estimate correctly the contribution of both technogenic factors and natural oscillations to the recent warming.

Rises in the released seismic energy during the fifth crisis is observed both in the entire central part of the Alpine–Himalayan orogenic belt and its individual seismotectonic provinces and main zones (Figure 9.11). Two peaks of the seismic energy release can be seen: in the second half of the 17th century and in the second half of the 19th century – the first half of the 20th century. If one takes into account an improvement in the registration in the 19th and, especially, 20th centuries, one cannot consider that the first peak was weaker than the second one. However, it is doubtless that the seismicity in the second half of the 20th century (after the crisis) was weaker than in the first half of the century (at the end of the crisis).

Therefore, the crises of the Oecumene were marked by aridization, sometimes accompanied by cooling in higher latitudes. Although these phenomena were not totally coincident in time among different regions, the epochs of climatic deterioration were common. There are grounds to suggest that climatic features of these epochs spread globally. Tectonics processes also activated during these periods. For the last three crises, this is reflected by the greater amount of the released seismic energy. Seismic activity peaks were observed in the beginning and the end of the fifth, fourth, and, perhaps, third crises. Fragmentary paleoseismological and geoarchaeological data allow us to suggest a similar seismic activation for the two earlier crises. It was accompanied by volcanic activity in Armenia and Syria.

Thus, the crises as social phenomena were prepared by the preceding evolution of human communities and, to a considerable extent, were determined by their inner conflicts and relationships with neighbors. On the other hand, deteriorating climatic conditions and tectonic activation were typical for all of the crises, and, apparently, contributed to their development.

9.3.4. Changes of the Caspian and Black Sea Levels as Manifestations of Tectonic and Climatic Rhythms in the Late Holocene

The Caspian Sea is a closed basin. An analysis of historical, archaeological, geological, and geomorphologic data gives one a possibility to reconstruct variations of the Caspian level for the last 2,700 years. The level was about -20 m in the 7th–6th centuries BC (Klige et al., 1998), but it fell down to -31 – -33 m in the 3rd–1st centuries BC (Kaplin and Selivanov, 1999). Then, the level rose to about the contemporary altitude, but it began to fall again from the early 5th century AD and reached -30 – -35 m in the 6th–7th centuries (the Derbent regression). From the second half of the 12th century, the level began to rise and reached -25 m or, perhaps, -21 – -22 m by the early 19th century (Rychagov, 1993). The rise ranged up to 8–9 m. Then, the level began to fall till 1977, and then it began to rise until 1998 (Section 9.2.1).

The Derbent regression had important historical consequences. The city of Itil was founded in the Volga delta in the first half of the 8th century as a capital of the Khazar State (Figure 9.12). According to the historical documents, the city included the ruler's castle in the island and the city itself running along the river over a length of 6 km. Up to 10,000 inhabitants lived in the city. The Russian prince Svyatoslav destroyed it in the years 965–966. In the late 970s, the Khazarians reconstructed part of the city. However, the Russian prince Vladimir finally won the Khazarians in the late 10th century, and Itil lose its role. The last record of Itil was dated by the 12th century as the town of the Ancient Turks. In spite of the exact historical description of the Itil location and its big size, archaeologists could not find it. Gumilev (1966) proposed that Itil was build during the Caspian regression and later was flooded and covered by the Volga sediments. Now this version seems to be doubtless.

The regression is proved by the position of the medieval constructions of the city of Derbent. The city defended the Transcaucasian provinces of Persia (Armenia and Albania) from the North Caspian nomads. In the mid-6th century, the shah Chosroes built the Derbent fortress and the protective wall between the mountain slope and the Caspian. Now a part of the wall is under water and its foundation is situated several meters below sea level.

The Baku fortress gives the chronological data on the end of the regression (Bretanitsky, 1970). Two coastal walls of the fortress stood the Mongolian siege in the first half of the 13th century. However, later the sea level began to rise quickly. Marino Sanuto the Elder, the Venetian geographer, wrote in 1320 that the sea rose '*to the palm per year and many good towns were flooded*'. The Arabian traveler Abd Ar-Rashid wrote in the early 15th century that the walls concerned were situated offshore and bordered the ship mooring. The German researcher Engelbert Kaempfer described the offshore position of the walls in 1683. The walls can be seen in his print as well as in the Samuel Gottlieb Gmelin's drawing of 1769. Later the sea regressed and the Maritime Boulevard and the Oilmen Avenue were built in the 20th century between the Old Town and the sea. However, the sea level rose after 1978 and flooded them partly.

The Caspian level changes for the last 2,500 years followed the general climatic changes in Eurasia with some delays. The Caspian transgressions in the 1st century BC – 5th century AD and the 12th–18th centuries followed the epochs of warming in the midlatitudes and some humidification in the Mediterranean, Middle East, and Central Asia in the second half of the 1st millennium BC – the 3rd century AD. The Caspian regressions in the 5th–12th and 19th–20th centuries followed the epochs of cooling in the midlatitudes and aridization in the southern regions in the 4th–8th and 16th–19th centuries. The delay can be caused by different influences of the climatic changes on the rivers flowing into the Caspian and the evaporation of the Caspian itself, because the rivers, main contributors, and the sea are situated on different latitudes.

The Black Sea is the semi-closed basin, which communicates with the Mediterranean Sea and the World Ocean via the system "Bosporus – Sea of Marmara – Dardanelles". A gradient between the more saline and denser Aegean waters and the more fresh and less dense Black Sea waters causes two contrary flows in the Bosporus: the demersal flow to the Black Sea and the surficial flow to the Aegean Sea. Now the Black Sea level is higher than the Aegean one. The surficial flow has the rate of 1.5 m/s containing almost twice more water than the demersal flow. As a result, about 183 km^3 of water pours annually out the Black Sea (Svitoch et al., 1998). The same relationships took place in the Holocene, but the intensity of the demersal flow could vary. For example, for the short epoch in the Early Holocene, it was probably more intensive than the surficial flow (Fedorov, 1978; Ryan et al., 2003).

The communication between the Black Sea and the Mediterranean interrupted or was restricted for some epochs of the Quaternary. Nevertheless, the Quaternary variations of the Black Sea level corresponded in general to variations of levels of the Mediterranean Sea and the World Ocean caused by the climatic changes (Fedorov, 1978; Svitoch et al., 1998; Kaplin and Selivanov, 1999). This is also true for the Holocene. For example, the Hadjibey regression of the Black Sea, dated by the mid-3rd millennium BC (Sadchikova and Chepalyga, 1999), corresponded to the epoch of the second crisis aridization. In this background, the Phanagorian regression of the Black Sea looks unusually.

The Phanagorian regression is proved by the archaeological data. The Ancient Greek towns, founded in the Black Sea coasts in the 6th–5th centuries BC, are partly submerged. Numerous data on the values of flooding were found in the towns of the northern Black Sea: Olvia in the Dniester mouth (Greek Hipanis), Chersoneses in the southwestern Crimea, and towns around the Kerch Straight (Cimmerian Bosporus – Figure 9.16). Some clusters of ceramics and ruins of constructions in Olvia and Phanagoria are submerged to >4 m (Blavatsky, 1967; Kaplin and Selivanov, 1999). Ruins of walls mark the northern flooded margin of Phanagoria in 220–240 m from the coast. Some constructions of Patrae of the 3rd century BC are situated now at the depths of down to 4–4.5 m (Abramov et al., 1998). In the city of Panticapaeum (present-day Kerch), the data were obtained on the flooded port constructions. The Ancient Greek ceramics were found by drilling at the depths of 3.5 m (Nikonov, 1998). Fedorov (1978) described ruins of the town of Nymphaion (Nymphaeum) at the depths of down to 6 m. He wrote about walls of the farmstead with ceramics of the last quarter of the 4th century BC. The walls continue into the sea now; they are covered by 2.2-meter layer of water. Shilik (1991) found ruins of the town of Acra at the depths of down to 3.5 m. The well excavated to 1.1 m was situated in 140 m from the coast and 3 m below sea level. It contained ceramics of the early 4th – early 3rd century BC. Shilik (1991) estimated the regression magnitude as >4.5 m. Residential and economic constructions were probably built not lower than 1–1.5 m above sea level to avoid influence of storm waves. Therefore, their present position 3.5–4.5 m below sea level means the regression magnitude of 5–6 m corresponding to the estimate by Fedorov (1978).

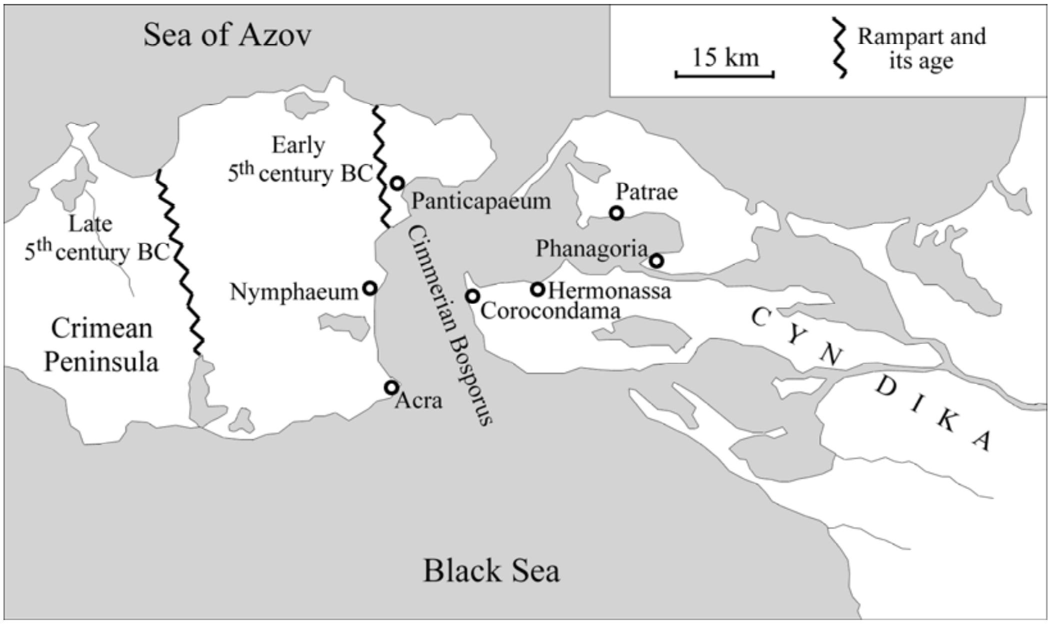

Figure 9.16. The Ancient Greek towns near the Cimmerian Bosporus (the Kerch Strait) (Trifonov and Karakhanian, 2004).

The rare evidence for the time of the beginning of the Phanagorian regression is the ^{14}C date 3,240 ± 60 (viz., 1600–1435 BC) of the marine sediments underlying the cultural deposits of Olvia. The marine sediments occur on the recent sea level (Shilik, 1977). Therefore, the regression began later. This was corroborated by the following data. According to the Myth of the Argonauts, sailing was difficult in the Bosporus in the 13th century BC (probably, because of the strong counter flow). However, according to Herodotus (1998, p. 264), the navigation did not meet any difficulties in the Classical Greek time (from the 7th century BC), when the regression had occurred and the flow rate had decreased.

In the 1st millennium AD, the regression was followed by the Nymphaeum transgression, when the sea level could reach +1.5–2 m, but it was, most probably, between 0 and +1 m. Fedorov (1978) described a stratotype of the transgression near the ancient town of Nymphaeum, where sands with the marine shells (about 1 m) overlay loam with ceramics and foundations of the town on the 2.5-meter terrace. By these data, Fedorov (1978) considered that the transgression began in the 5th century AD, but it is not quite correct. The estimates of the regression magnitude are based on the present position of the Classical Greek layers and constructions (the 5th–2nd centuries BC). However, Shilik (1977) quoted Dio Chrysostomos' data that the sea-level rise began in Olvia in the 1st century AD. The economic zone of Patrae, partly covered by water now, spread in the 1st century to the smaller part of the Taman Bay than the zone of 550–270 BC (Abramov et al., 1998). Obviously, the transgression began in the 1st century AD and reached its maximum in the mid-1st millennium. Therefore, the Phanagorian regression began probably during the third crisis and finished during the fourth crisis.

The data on the Mediterranean and some coasts of the World Ocean showed that the sea level was 2–3 m lower than now during the Phanagorian regression, and rose up to the recent level or could be higher to ~0.5 m in the mid-1st millennium AD during the Nymphaeum transgression (Butzer, 1958; Trifonov and Trifonov, 2006; Trifonov and Karakhanian, 2008). In the Black Sea, the regression reached 5–6 m and the "Nymphaeum" sea level was 0 to +1 m. Therefore, the contrast between the sea levels during the regression and the following transgression was ≤3 m in the Mediterranean and reached ~6 m in the Black Sea. It is necessary to explain the 3-meter difference between these values.

The 2–3-meter regression in the Mediterranean, communicating with the World Ocean, could be caused by some global climatic changes. The simplest explanation of the regression in the Black Sea could also be the climatic change: a decrease of river flowing and/or an increase of evaporation due to the warming in the 1st millennium BC continuing possibly until the 1st or 2nd century AD. As a result, the surficial flow from the Black Sea to the Mediterranean would decrease, and salinity of the Black Sea water would increase.

However, the oxygen isotopic data demonstrated the contrary situation: the $\delta^{18}O$ values were lower for the regression than the following transgression (Svitoch et al., 1998). This means that some desalting took place and the Black Sea level continued to be higher than the Mediterranean one during the regression. So, the latter could be caused only by reduction of the salt demersal flow to the Black Sea that could depend on reduction of the Dardanelles or Bosporus depth.

Although the Dardanelles is crossed by the North Aegean active fault (Pavlides, 1996), which generated earthquakes with $M_S > 7$, it seems to be doubtful that the seismotectonic deformation could reduce the demersal flow essentially because the strait is wide and deep enough. The Bosporus represents a system of small basins and bulkheads with the minimum depth of 27.5 m that are cut by active faults branching out the North Anatolian fault zone. Numerous historical strong earthquakes justified their activity (Trifonov and Karakhanian, 2004).

Seismic shifts and landslides could deform the Bosporus bathymetry. Such deformation has two limitations. First, it could not be too big to produce quick flow and erode the soft Pleistocene sediments on the strait bottom. Second, the deformation was not accompanied by essential reduction of the strait width. Herodotus (1998, p. 263) presented the data on width of the strait in the site, where the Persian army of the King Darius crossed the Bosporus in the 5th century BC. The width was four stades (about 710 m) that coincides with the recent width (660 m), considering inaccuracy of the measurement.

We proposed the following hypothetical explanation of the 3-meter difference between values of the Phanagorian regression and the synchronous regression in the Mediterranean (Trifonov and Trifonov, 2006): Seismic activation for the third crisis reduced a depth of the Bosporus in some bulkhead. It was enough to reduce the demersal flow of the salt Mediterranean waters and correspondingly the salinity of the Black Sea. The difference between levels of the Black Sea and the Mediterranean and related rate of the surficial flow from the Black Sea reduced that improved the navigation in the Classical Greek time. Seismic activation for the fourth crisis (the Byzantine tectonic paroxysm) restores the former demersal flow and later the Black Sea water balance approached to the recent conditions. Thus, the peculiarities of the Phanagorian regression were caused by seismotectonic events during the third and fourth historical crises.

9.3.5. Stages of the Slavdom Generation and Development of the Russian State in Relation to Tectonic and Climatic Rhythms in the Middle and Late Holocene

Were the Late Holocene natural and historical crises manifested in the generation of the Slavic ethnos and the East Slavic (Russian) political body? Positive answer to this question would mean that the crises were typical not only for the tectonically active Alpine–Himalayan orogenic belt, but also for the territories with weak neotectonic movements and rare earthquakes (e.g., the East European Platform). If the natural factors influenced on the social and political situation in such territories, they were mainly climatic changes.

The Cucuteni–Tripolie agricultural community (Figure 9.12) was the top of the Chalcolithic producing economics in southeastern Europe (Masson, 1999). The culture was formed in the late 5th – early 4th millennia BC. In the second part of the 4th millennium BC and particularly in the first half of the 3rd millennium, being in the stage of mature flourishing, the Cucuteni–Tripolie people contacted with the steppe semi-nomadic tribes, which spread from central Europe up to the Volga region and the Southern Urals and created the megalithic Kurgan cultures (Figure 9.12). Some researchers consider them by the ancestors of the Aryan, Ancient Greek, and Armenian peoples. Using archaeological data, Danilenko (1974) and Rybakov (1981, p. 204) found some cultural and ideological features of the Tripolie inhabitants similar with the Rigveda texts and the features of the later Indo-European cultures of the Bronze Age. Perhaps, the Tripolie inhabitants also belonged to the Indo-Europeans. Rybakov (1981) demonstrated presence of the Tripolie images in the folk art of the East Slavs till the 19th century AD.

The Cucuteni–Tripolie culture degenerated by the mid-3rd millennium BC. It was followed by the Usachevo culture (the 25th–24th centuries BC) collapsed by the late 3rd millennium BC. The decline of the Cucuteni–Tripolie culture and synchronous degradation of the similar Balkan agricultural communities coincided with the mass migration of steppe peoples from central Europe to northern Kazakhstan. In the second half of the 3rd millennium, the Yamnaya culture (Figure 9.12) was formed there, probably, by the Aryan ancestors. Approximately at the same time (the 27th–22nd centuries BC), the Globular Amphorae culture and the Corded Ware culture (also known as the Battle Axe or Single Grave culture) arrived in southern Europe. The distinctive feature of these and similar cultures was domination of cattle breeding with herdsmen in horses and social layering with separation of political leaders and fighting riders. However, these mobile tribes continued to be semi-nomadic and combined cattle-breeding with agriculture (Rybakov, 1981).

The decline of the earlier agricultural communities, built in principles of the primitive equality, and spreading of the semi-nomadic cultures manifested transition to the Bronze Age and fundamental changes in technology, economics, and organization of the society. The patriarchy, heliocentric system, and idea of an immortal soul were originated at the same time (Rybakov, 1981). All these changes coincided with the *second historical crisis* corresponded to the end of the Atlantic period and characterized by cooling and aridization.

An estimation of the influence of this crisis on the Slavic ethnogenesis depends on the concept of Slavic motherland. Trubachev (2002) argued an opinion that pre-Slavic cultural linguistic community separated from the Indo-European language family in the late 3rd – early 2nd millennia BC in the Middle Danube region. Some scholars extend this area to the entire Danube–Balkan region including even the North Carpathians. The decline of the Balkan and

Cucuteni–Tripolie earlier agricultural communities could promote the separation. The Polish and some Czech scientists argued the Vistula–Oder concept of the Slavic motherland (Parczewski, 2003). It was covered by the Oder–Dnieper concept including the Pripyat–Dnieper region to the Slavic motherland (Niederle, 1902–1924; Rybakov, 1981). By the last concept, peoples of the collapsed Cucuteni–Tripolie and Usachevo cultures, which migrated to the north, could participate in the generation of the pre-Slavs. The creators of the globular amphorae and corded ware could also participate in this process. Therefore, independently on the pre-Slavic motherland concept, the Cucuteni–Tripolie culture contributed to the Slavic generation.

The earliest certainly pre-Slavic culture was the Trzciniec one formed and existed in the 17^{th}–13^{th} centuries BC in the upper Vistula and Oder basins. Rybakov (1981) spread it to the southeast and named the Trzciniec–Komarovo culture. The latter corresponded exactly to the Oder–Dnieper territory of the pre-Slavic motherland. The culture included traditions of the earlier agricultural population as well as the semi-nomads and was characterized by a slow rate of development. The flint tools predominated; the bronze was rear, probably, because of remoteness of its sources.

The important changes took place in the pre-Slavic area in the epoch of the *third crisis*. The development accelerated in the 13^{th} century BC. The western part of the pre-Slavs became a part of the Lusatian culture considered by some scholars as the ancestor of the German, Baltic, and Slavic tribes (Rybakov, 1981). Just in this culture, the local population began to use the iron. These changes took place also in the eastern part of the pre-Slavic area but a little later. Signs of the iron industry arrived there in the Belogrudovsky culture (the 12^{th}–11^{th} centuries BC) and became usual in the Chernolesskaya culture (the 9^{th}–8^{th} centuries). The second important change was the restoration of the leading role of agriculture modernized with plough.

Rybakov (1981, p. 263) characterized this epoch as follows: '*A stagnated rate in the development of the Trzciniec tribes was changed by the swift movement in the Chernolesskaya time. It was the second jump after the Globular Amphorae and Corded Ware epochs. That first jump had been triggered by arrival of the bronze and the herdsman cattle-breeding, whereas the second jump was stimulated by the intensification of the tillage plough agriculture and the discovery of new metal, the iron*'. Transition to the iron industry was very important for the pre-Slavs. Deposits of copper and tin were absent in their area and bronze was imported from the steppe. The iron minerals and the charcoal fitting the Iron Age technology were abundant in the pre-Slavic territory. This caused jump in the pre-Slavic development.

Divergence of the Slavs to the western and eastern branches was initiated by inclusion of the western part of the pre-Slavs to the Lusatian cultural community, the struggle of the eastern part of the pre-Slavic tribes with the Cimmerians in the 9^{th}–8^{th} centuries, and the Scythian influence in the 7^{th}–3^{rd} centuries (Rybakov, 1981). Even when the branches converged (e.g., in the 3^{rd} century BC – 3^{rd} century AD), their differences remained in traits of the western Przeworsk and eastern Zarubintsy cultures.

The third crisis was characterized by the transition of burial rites: from a bent position to cremation (Rybakov, 1987). The former meant reincarnation and was linked with the agrarian cycle, the latter meant transference of the deceased to the heaven, where the soul could help to ensure the good weather (e.g., a timely rain). On the other hand, the fertility of soil was not forgotten as remains of the cremated deceased were buried in special urns. Perhaps, the attention to the meteorological factors of the agricultural productivity was caused by some aridization during the third crisis.

According to Rybakov (1987), the further development of the eastern pre-Slavs was characterized by the culture of Skolots (Scythian-ploughmen, Borysthenites – Figure 9.12) and the Milograd culture of the 7th–4th centuries BC as well as the Zarubintsy (the 3rd century BC – 3rd century AD) and Chernyakhov (the 2nd century AD – the first half of the 5th century) cultures. The Skolots occupied not only the eastern part of the Oder–Dnieper motherland, but also some southern forest–steppe territories. Rybakov (1987) explained this spreading by peaceful relations with the Iranian-language Scythian nomads and close links with the Greek city of Olvia due to the grain trade. Rybakov (1987) identified the more primitive Milograd culture with Neurian tribes of Herodotus (1998, p. 276).

The Sarmatian invasion stopped these social and cultural successes and led to the migration of the pre-Slavs to the northern forest zone, where they formed the more primitive Zarubintsy culture. The further joining of the Black Sea coasts to the Roman Empire caused coming back of a part of the pre-Slavs to the southern lands and their agricultural and social progress on the basis of trade and cultural links with Rome via Olvia (the Chernyakhov culture – Rybakov, 1987).

The *fourth crisis* was characterized by the decline of the Chernyakhov culture and the mass migration of the Slavs (the second half of the 5th century AD – the first half of the 8th century). The Slavs populated the Balkan Peninsula (the Southern Slavic branch) and spread to the northeast to the territories with the rare Baltic and Ugro-Finnish population (Gumilev, 1989). The basis of the state system was formed in the Middle Dnieper, in the main body of the East Slavic inhabitance. It was resulted by the creation of the powerful East Slavic (Old Russian) state in the 9th century (Rybakov, 1982). The further historical events are well known: the development and decline of the Old Russian state (Kievan Rus), the Tatar-Mongol invasion, and the revival of the united state as the Grand Duchy of Moscow.

The last *fifth crisis* lasted in the Russian territory from the late 16th century till the late 19th century. It coincided with the Little Ice Age. Beginning of the cooling was marked by several years of bad harvest in the end of reign of Ivan IV the Terrible and during the reign of Boris Godunov. The northern territories, having been formerly by important agricultural regions and subjects of wars to hold them between the princes, lost population. The cooling and correspondingly bad harvests led to starvation and became one of the factors of chaos during the *Time of Distemper* in the early 17th century. Beginning of the crisis led to migration of people to the southern margins of the Moscow Russia and initiated the search for new ways of existence. One of them was colonization of Siberia. It continued during the 17th century and finished in the 18th century by establishing Russian America (Solov'ev, 1960–1964). Because of the first stage of the crisis, the Russian Empire was formed and strengthened. The dramatic Russian history of the 20th century represents the final stage of the fifth crisis and its consequences.

The fifth crisis was manifested in the North Atlantic by strong cooling. The Danish Strait was filled in ice and the communication with Iceland was essentially difficult already in the 16th century. As a result, the Norman colonies in North America and Greenland perished. The population of Iceland degraded and lost navigation experience. When the Danish seamen arrived there in the early 17th century, they found only about 30,000 inhabitants lived in miserable ground houses and engaged in cattle breeding. The reduction of the population from ~120,000 in the 11th–13th centuries down to ~30,000 in the 17th century was induced by not only the cooling, but by volcanic eruptions as well (Thorarinsson, 1967). The cooling was probably caused by the degradation of the western branch of the Gulf Stream. However, its eastern branch continued to exist. It turned round the Scandinavian Peninsula, causing its high moistness and growth of glaciers, and followed to the Kara Sea making it navigable in the summer season. The port of Mangasea on the southern coast of the Kara Sea acted in the 17th century. However, the situation changed in the early 18th century: the expedition sent by Peter I could not reach even the islands of Novaya Zemlya because of abundant ice. In the 20th century, the warming took place in Russia: the average near-ground temperature rose to 0.9° C from 1891 to 1998 (Losev, 2001). The warming accelerated for the last decade.

Therefore, the epochs of the second to fifth natural and social political crises in the Eastern Oecumene during the second part of the Holocene coincided with the principal stages in the generation of the Slavic ethnos and the East Slavic (Russian) political body. The second crisis marked the transition from the Chalcolithic to the Bronze Age and led to the separation of the Pre-Slavs from the Indo-European community. The Pre-Slavs inherited relics of earlier agricultural economy and skills of pastoral stockbreeding formed during the crisis. The third crisis marked the transition from the Bronze Age to the Iron Age and, possibly, determined certain isolation of the eastern and western branches of the Pre-Slavs. The fourth crisis included settling of the Slavs in the Balkan Peninsula, spreading the East-Slavic population to the northeast, and laying foundations of the future East Slavic statehood in its core. Finally, the Russian Empire, covering vast areas of the Northern Eurasia, formed during the fifth crisis after the *Time of Distemper,* whereas dramatic search of new ways took place later, in the 20th century.

The crises were separated by long periods of stable co-existence of large cultural communities or states, some of which were multi-ethnical. Among them are the Cucuteni–Tripolie and Trzciniec–Komarovo cultures, the union of the Skolot tribes, Kievan Rus, the Tsardom of Russia, and partly the Russian Empire in the time span between the two peaks of the last crisis. Unlike these stable epochs, the crises were characterized by social and economic upheavals, dissolution and reconstruction of existing communities, mass migrations, and rapid changes determining transitions of the society to a qualitatively new level.

The coincidence of the crises in the Eastern Oecumene and the East European Platform is the serious argument for the global character of the crises.

9.3.6. Origin of the Medium-Period Climatic and Tectonic Variations

The Middle and Late Holocene climatic variations had different duration and were not synchronous in different parts of the Eastern Oecumene and eastern Europe. However, we identified the epochs when the climatic changes were unidirectional in most regions; such epochs correspond to the historical crises. The seismicity also varied in the Eastern Oecumene. Most seismic zones were marked by seismic cyclicity with the periods of 200–300 or 500–700 yr; cycle phases could not correspond to each other in different zones. However, we identified the common seismic super-cycles, which include the epochs of seismic activation corresponding to the crises. Thus, the synchronous tectonic–climatic cyclicity took place in the Middle and Late Holocene. The ~300-yr critical phases of the cycles repeated every 1,200–1,800 years.

The influence of astronomic factors on the medium-period cyclicity of natural and social events has been discussed in the scientific literature. Among such factors are peculiarities in the rotation of the Earth and its layers, the Sun–Moon–Earth gravitational interaction, and variations of solar activity. For example, Mikulecký (2007) demonstrated relations between 500-yr cyclicity of solar activity and social and cultural development of the society. By duration, the tectonic–climatic–historical cyclicity discussed in this chapter is similar with the Shnitnikov (1957) rhythms of humidification in the Middle and Late Holocene having periods of 1,500–2,000 yr. The 1,500–1,900-yr fluctuation were found in ocean level changes (Selivanov, 1996). They were probably caused by the climatic variations. The climatic rhythms correspond to the periods of constellation of the Moon, Earth, and Sun, when the tidal force can increase to ≥10% (Shnitnikov, 1957). This could change the oceanic circulation and influence the seismic activity. However, most scientists did not recognize Shnitnikov's ideas.

Archaeomagnetic studies by Burlatskaya (1987) seem to be very important for the cyclicity discussed. She analyzed the Holocene changes of intensity, inclination, and declination of the geomagnetic field. In the temporal spectra of these parameters, she found typical cycles with periods of 360 ± 40, 600 ± 50, 1,200 ± 50, and 1,800 ± 70 yr (Table 9.3). Considering a reduced number of archaeomagnetic observation of the long duration (enough to identify the cycles with periods of 1,200 and 1,800 yr), Burlatskaya (1987) concluded that the 1,200-yr cycle was the most typical (Figure 9.17).

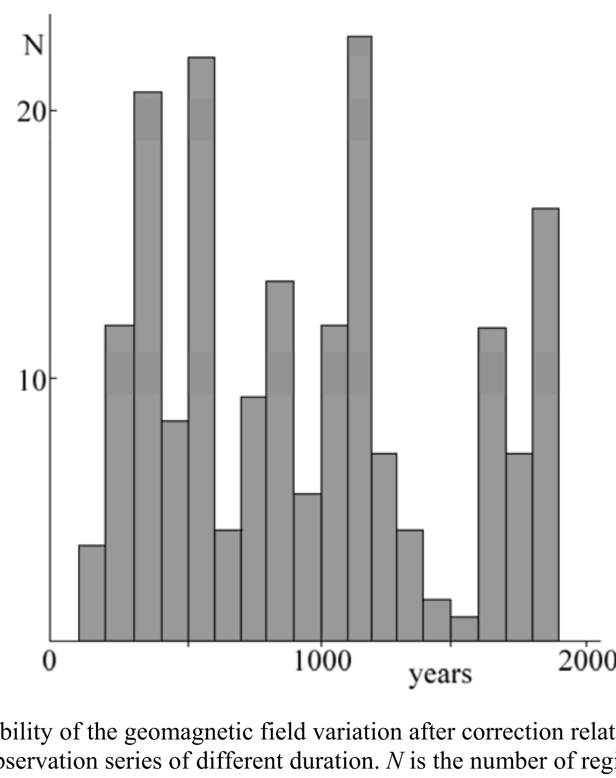

Figure 9.17. Repeatability of the geomagnetic field variation after correction related to different representativity of observation series of different duration. *N* is the number of registered cycles of variation in the representative series of observation. The figure was compiled using data from (Burlatskaya, 1987).

Table 9.3. Magnitudes of the geomagnetic field variations (Burlatskaya, 1987)

Period, yr	Intensity, μT	Inclination, degree	Declination, degree
1,800	4–6	2	5–10
1,200	4	2–5	6–8
600	4	1–4	3–5
300–400	2–4	1–5	3–8

The 1,200-yr cycle was credited to the precession of the geomagnetic axis around the Earth's rotational axis at angular velocity of 0.3°/yr (Burlatskaya, 1987; Burlatskaya and Ermushev, 1994; Burlatskaya et al., 2006). The 1,800-yr cycle is associated with the global component of the western shift of the geomagnetic axis (Burlatskaya, 1987). Thus, the tectonic–climatic cyclicity discussed is synchronous to the oscillation of geomagnetic activity, which is probably caused by the difference in the rotational velocity of the liquid outer core and mantle.

9.4. Conclusion

At a regional scale, it is demonstrated that periodic changes of the Caspian Sea level are the combined result of the water balance variations (mainly caused by climatic changes) and the recent tectonic activity partly manifested by seismicity. The influence of active tectonics consists in the integral effect of various deformations producing periodic changes of the Caspian reservoir volume, and probably variations of the groundwater recharge. Studies in various regions proved that the 11-yr and multiple-of-11-yr cyclicity is the most significant among the recent short-period variations of climatic and tectonic activity. This cyclicity influences the economic activity of the society.

The ~1,200-yr (~1,800-yr in one case) cycles are the most important among the medium-period variations of climatic and tectonic activity in the Middle and Late Holocene. These cycles contributed into the historical crises, which were characterized by social unrest and mass migrations, and changed the balance of political forces. On the other hand, crises determined breakthroughs to new technologies and new forms of economical and political relations. The crises were manifested in both the Alpine–Himalayan orogenic belt and the East European Platform. Perhaps they covered the entire Northern hemisphere.

Synchronism of climatic and tectonic events in both short- and medium-term oscillations is possibly caused by the difference in the rotational velocity of the liquid outer core and mantle (the dominant factor), periodic changes in the Earth's orbital parameters, as well as solar activity. Multiple-of-11-yr cycles correlate with the periodic changes in solar activity, whereas the 1,200-yr cycle is associated with the precession of the geomagnetic axis around the Earth's rotational axis.

To provide the sustainable development of humanity, the short- and medium-period variations of climatic and tectonic activity should be considered in construction projects, land use, agriculture, people's security, and geopolitics.

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