Ancient and Modern Earthquake Lights in Northwestern Turkey

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INTRODUCTION

Before dawn on 17 August 1999 one of the greatest earthquakes in modern Turkish history occurred on the historically active North Anatolian Fault (Ambraseys, 2002). The epicenter lay near the town of Izmit in Kocaeli province, not far east of Istanbul (ancient Constantinople). At Gölcük on the eastern shore of the Sea of Marmara, an eyewitness reported that "the earth came alive with shaking, the sky turned red, a sword of light flew out of the sea" (Gore, 2000). Rothaus *et al.* (2003) interviewed many other Gölcük eyewitnesses, who independently confirmed that "the sky glowed red" and "the sea glowed red" during the shaking. Since the night was overcast, the investigators could not determine whether the sky glow was atmospheric in origin or was merely cloud-reflected light emitted by a glowing sea.

In addition, circular and irregularly shaped lights of white, yellow, red, and blue were videotaped for several minutes near the earthquake epicenter on 25 July, as well as farther to the west, near where the fault line ends, on 16 August (Erkmen, 2001). Barka's (1999) report of "a ball of flame and the sound of an explosion" at the time of the earthquake was later explained as being due to sea mine explosions and to oil refinery fires, although the peculiar "balloons of strong light coming out of the sea" for several days afterward are still under investigation (E. Erkmen, personal communication, 2003). The various lights were widely reported throughout the Turkish media.

The sky coloration and the anomalous lights recall a long attested, but poorly understood, epiphenomenon of large earthquakes called "earthquake lights" (Derr, 1973, 1986). Although there are many suggested causes of earthquake lights, the phenomenon in the Izmit instance might conceivably be attributed to an explosion of ground-sequestered methane (marsh gas) (Barka, 1999) or of deep-water hydrogen sulfide (Degterev, 2001), or even be traced to a surface electromagnetic field variation that was actually measured at the time of the earthquake (Matsushima *et al.*, 2002), since such a field variation might produce a large-scale visible discharge in the air (Freund, 2003). Another possibility is that natural gas migrated upward from the underlying area oil fields through rock fissures and then ignited in the atmosphere (or in the sea) or glowed by electricization (Khilyuk *et al.*, 2000).

The eastern Mediterranean and Black Sea areas have experienced apparent earthquake lights on several other occasions in modern times. Reported observations in Greece include fires descending from the sky at Zante in 1729, a glowing ball moving in the sea there in 1820, a flash of light accompanied by a sulfur smell in the Peloponnese in 1886, flashes rising from the ground on Cyprus in 1896, and a red luminous band streaking across the sky near Corinth in 1995 (Papadopoulos, 1999; Soter, 1999). A well investigated earthquake in eastern Romania in 1940 was accompanied by predominantly red (in some places white or blue) luminous glows and, in other places, by rising ground flames as if from a gas (but not actually burning) (Demetrescu and Petrescu, 1941). Similar phenomena have been reported from elsewhere in the world over a long period of time (Galli, 1910; Montandon, 1948). Especially careful investigations have been made after modern earthquakes in Japan (Musya, 1931, 1932; Terada, 1931; Yasui, 1973; Tsukuda, 1997), China (Wallace and Teng, 1980; Deng *et al.*, 1981), and Québec (Ouellet, 1990; St-Laurent, 2000). Some lights have even been photographed (Yasui, 1968; Derr, 1973; Hedervari, 1984; St-Laurent, 2000; Erkmen, 2001), so their physical existence is now beyond doubt.

Summarizing the salient aspects of earthquake lights, they can be seen only at night, briefly (for just seconds or minutes), and only in association with earthquakes of large magnitude ($M > 5$) and of shallow focal depth. On the other hand, they cover a fairly broad zone in space and time, ranging up to hundreds of kilometers from the epicenter and occurring, for some earthquakes, over a period of days before and/or after the mainshock. These characteristics serve to distinguish them from other classes of atmospheric phenomena with which they might be confused, but only if the earthquake events have been carefully observed and reported.

Although the existence of earthquake lights is no longer speculative, current seismological research has mainly focused on acquiring instrumental, rather than anecdotal, measures of structural and electromagnetic changes in the Earth. Therefore, much more documentation of the rarest visible (and audible) phenomena is needed, and this can come, for now, only from historical records or from personal interviews of witnesses after modern earthquakes.

The present paper is concerned with the earliest existing reports of earthquake lights. A cut-off date is set at approximately A.D. 600. To restrict the present survey to original accounts that are specific enough to be accurately evaluated and dated, all mythological and biblical accounts of earthquakes have been omitted. The reporting area is confined to the Mediterranean basin and the Middle East. For dates of earthquakes, reliance has been placed mainly on the earthquake catalog of Guidoboni *et al.* (1994).

Four previous publications contain significant mentions of ancient and medieval accounts of what might be termed earthquake lights. Galli (1910) collected many accounts of possible earthquake lights from classical antiquity on. For the present period of interest, he briefly presented fifteen potential candidates, of which he rejected at least six. Listed or discussed here will be his best cases—461–459 and 91 B.C., and A.D. 17, 365, 395–402, 447/450, and 526—together with five additional cases not mentioned by him.

Tributsch (1982) less systematically discussed historical accounts of many unusual earthquake phenomena. These included earthquake lights, of which he mentioned possible candidates in 91 B.C., A.D. 365, and A.D. 447/450 and added some instances of biblical "lights" as well as some entirely isolated reports of "lightning in a clear sky." Although the latter two categories can be treated here as probably irrelevant, his three best cases will be tabulated below.

Guidoboni *et al.* (1994) published a detailed and annotated earthquake catalog up to the year A.D. 1000. Only a few accounts referring to possible earthquake lights are quoted, however: those for 91 B.C. and for A.D. 17, 395–402, 447/450, 502, 526, and 557, among which some attention to the lights is drawn only in the cases of 91 B.C. and A.D. 17, 395–402, and 502.

Papadopoulos (1999) briefly suggested ten candidates, selected mostly from secondary sources. A more critical selection, with full documentation from the original sources, will be presented here for the cases of 373 B.C. and for A.D. 395–402, 447/450, 502, 526, and 557. Rejected here are what are almost certainly a comet in 427/426 B.C., a building construction fire in A.D. 363, a thunderstorm in A.D. 499, and a great city fire in A.D. 525, as can be verified from the original sources cited by Guidoboni *et al.* (1994).

Other authors have associated at least one of the more promising cases with earthquake lights. For example, Sordi (1989) discussed the case of 91 B.C., and Derr and Persinger (1992) that of 373 B.C.

The purpose of this new study is to present the most reliable ancient and early medieval evidence for earthquake lights. The intent here is to exploit the historical sources for further anecdotal information, in order to provide additional source material and to demonstrate the common properties of the sightings through time.

It is not possible, however, to ascertain the full range of types of earthquake lights in antiquity. Unless there is an explicitly reported association with an earthquake, we have no way of knowing whether any of the isolated accounts of sky fire, ground flames, fireballs, etc. might be earthquake lights. Oftentimes, recorded circumstances confirm that these phenomena arose from thunderstorm activity, auroral displays, volcanic eruptions, and so forth, and such cases are ignored here, as are cases that are so vague that they could be almost anything.

Among the possible cases, two are plausibly argued to be the real thing. These occurred in the period A.D. 395–419 and may actually refer to the same event. Observations come from ancient Constantinople and are comparable with those from modern Izmit.

REPORTS OF POSSIBLE EARTHQUAKE LIGHTS

Ancient natural philosophers are notably reticent about earthquake lights, although they discuss many other epiphenomena of earthquakes. Earthquake lights are very rare and short-lasting, and seem never to have been recognized as an inherent earthquake phenomenon, even by those ancient authors who mention lights of various kinds at the times of earthquakes. In all known cases, any lights were explicitly taken to be either completely unrelated cosmic or atmospheric phenomena, or else industrial and domestic fires set off by the earthquake.

The only remotely possible notice by an ancient natural philosopher occurs in a theory of Anaxagoras, who, around 450 B.C., speculated that *aether* (the fiery upper air), having fallen into hollows in the Earth and trying to rise, causes earthquakes (Aristotle, circa 330 B.C.; Hippolytus, circa A.D. 234; Diogenes Laertius, circa A.D. 250). He may have connected the great earthquake that leveled Sparta at some date in the period 469–464 B.C. (Guidoboni *et al.*, 1994) with the brilliant auroral displays of the same period (Stothers, 1979). What interests us here, however, is his view that the earth-trapped *aether* sometimes succeeds in escaping (Seneca, A.D. 65). Although this may be an Anaxagoran reference to earthquake lights, the philosopher is more probably alluding to those earthquakes that accompany volcanic eruptions (Gershenson and Greenberg, 1964).

Tributsch (1982) has argued that Aristotle's subterranean *pneuma*—rushing winds that were argued to cause earthquakes—was in reality electrostatically charged air and hence the source of earthquake lights and earthquake fog. Aristotle (circa 330 B.C.), however, defines *pneuma* as the warm and dry exhalation of the Earth that pushes on ordinary air to set it in motion and thereby create a wind. The fogginess that he says occurs at the time of an earthquake is attributed by him to the absence (not the presence) of *pneuma* in the atmosphere: "The Sun is necessarily foggy and faint when the *pneuma* that dissolves and rarefies the air begins to withdraw into the Earth."

TABLE 1 Reports of Possible Earthquake Lights before A.D. 600				
Date	**Location**	**Observation**	**References**	**Alternative Explanation**
461–459 B.C.	Rome	Lights in sky	Livy 3.10.6; Dionysius of Halicarnassus 10.2.3	Aurora (Stothers, 1979)
373 B.C.	Greece	Fiery beam in sky for several nights	Seneca, *NQ* 7.5.3-4; Diodorus 15.50.2; Elder Pliny 2.96; Aristotle, *Mete.* 1.6	Aurora or comet (Stothers, 1979)
91 B.C.	North or central Italy	Flame from ground (in daytime)	Plutarch, *Sulla* 6.6; Obsequens 54; Orosius 5.18; Elder Pliny 2.199	Eruption (Guidoboni *et al.*, 1994)
A.D. 17	East Mediterranean	Fires amid ruins	Tacitus, *Ann.* 2.47	Burning cities
A.D. 360–363	Shaina, Egypt	Light in prison	Jerome, *Monks* 9	Apocryphal (cf. *Acts* 12:7, 16:26)
A.D. 365	East Mediterranean	Repeated lightning	Ammianus Marcellinus 26.10.15	Electrical storm
A.D. 395–402	Constantinople	See main text		
A.D. 419?	Constantinople	See main text		
A.D. 447/450	Constantinople	Fire in sky	*Easter Chronicle* 317, 319	Aurora or lightning
A.D. 502	East Mediterranean	Fire in north sky the whole night	Joshua the Stylite 47; James of Edessa, *Chron.*	Aurora (Wright, 1882; Russell, 1985; Trombley and Watt, 2000)
A.D. 526	Antioch	Rain of fire	John Malalas 419; John of Ephesus 299; Marcellinus Comes 526	Burning city (*cf.* Marcellinus)
A.D. 557	Constantinople	Glowing hazy air	Agathias 5.3	Burning city

The ancient and medieval references to possible earthquake lights are listed in Table 1. Two instances are so convincing that they are now discussed in detail.

A remarkable event took place in Constantinople one evening around A.D. 400: "At the beginning of night as the world was already growing dark, a fiery cloud was seen in the east. At first small, it subsequently increased little by little as it approached the city until, huge and awesome, it hung terribly over the whole town. A horrible flame seemed to droop from the sky, and the smell of sulfur was not absent. … In the same way that the cloud had increased in size, it began to diminish and gradually shrank away" (Augustine, circa A.D. 410). We are told that the cloud did no damage to the city.

Augustine delivered this detailed account in a sermon at Carthage, shortly after the Visigoths' sack of Rome in 410 (Hill, 1995). He was referring to an event that was associated with an earthquake explicitly by his pupil Orosius (A.D. 417). The date of the earthquake is disputed but must almost certainly lie between 395 and 402 (see the discussion in Guidoboni *et al.*, 1994). Although Augustine was not present in Constantinople during the earthquake, he later met at Carthage a few of what must have been thousands of eyewitnesses. Perhaps because it had not been an earthquake that had destroyed Rome, Augustine might have felt it irrelevant to mention explicitly the earthquake that had struck Constantinople. This earthquake is noted in the much briefer account of Orosius (A.D. 417): "The earth below, shaken to its depths, trembled, and a flame above spread over the heavens and hung down." Another contemporary, the poet Claudian (circa A.D. 399), also refers to both a crimson cloud in the sky and an earthquake around this time. Brief mention is later made in the *Gallic Chronicle* (Anonymous, A.D. 452) and, possibly, in Marcellinus Comes' (A.D. 534) *Chronicle*.

Modern commentators have volunteered several different interpretations of the sky fire but have never given any scientific justification for their choices. Most have interpreted it as the aurora borealis (Perrey, 1850; Seeck, 1920; Demougeot, 1951; Grattarola, 1989). Cameron (1987) interpreted it as a volcanic eruption, yet there are no volcanoes located near Constantinople (Simkin and Siebert, 1994). Galli (1910) rejected the phenomenon as earthquake lights, but Papadopoulos (1999) accepted it. Others offer no opinion one way or another (Hubaux, 1948; O'Reilly, 1955; Guidoboni *et al.,* 1994; Hill, 1995). We suggest here earthquake lights.

The key may lie in the details: the easterly direction of the cloud, the red sky, the sulfur odor, and the earth tremors (since, following Orosius, the earth tremors are associated with the other phenomena). These features may well point to the emission and burning of sulfur-rich natural gas from a sudden rupture along the North Anatolian Fault to the east. Although the sulfur odor might have been due to some gas other than hydrogen sulfide, which is second only to methane (an odorless gas) as a major component of natural gas, any alternative—such as the nitrogen oxides—seems less probable, because nitrogen oxides are normally absent from natural gas (although they can be produced in an electrically charged atmosphere) and especially because the Black Sea area is enormously rich in natural gas. The smell of sulfur has also been reported during a number of other earthquakes in various parts of the world, including Hungary, Italy, Venezuela, Perú, Chile, the United States (New Madrid), and China (Sungpan-Pingwu) (Tributsch, 1982; Gold and Soter, 1985). These regions, except for New Madrid, either have natural gas and petroleum deposits or are actively volcanic. On the other hand, no sulfur smell was reported for the great Romanian earthquake of 10 November 1940 (Demetrescu and Petrescu, 1941), which might imply that an electrical phenomenon caused those earthquake lights, as in the case of the Québec earthquake lights of 1988–1989 and the North Carolina lights of 1811, which occurred in gas-poor, nonvolcanic regions (Hough, 2000; St-Laurent, 2000). Based on these various examples, the reported details of the earthquake of 395–402 suggest that, in this case, the earthquake lights were caused either by burning natural gas or by electrical discharges in the air.

Another clue favoring natural gas comes from a phenomenon associated with the destructive earthquake of A.D. 358 at Nicomedia (modern Izmit): "On 24 August, at the first break of day, condensed globs of black clouds obscured the face of the sky, which a little before had been bright; the Sun's splendor was reduced, and things close by or even within reach could not be made out, so restricted was the range of visibility, as a squalid, dense fog rolled in and settled over the ground" (Ammianus Marcellinus, A.D. 391). The earthquake then occurred; slightly more than two hours later, the fog dissipated. This earthquake fog bears a close resemblance to the one reported at the time of the Haicheng, China earthquake of 4 February 1975, which Gold and Soter (1985) have interpreted in terms of subterranean gas emissions. On the other hand, Tributsch (1982) and Freund (2003) prefer, for both earthquake fog and earthquake lights, an explanation based on electrically charged aerosols or ions. Another possible earthquake fog occurred in A.D. 557 on a December night in Constantinople: "The surrounding air grew dim with the vaporous exhalations of a smoky haze rising from an unknown source, and gleamed with a dull radiance" (Agathias, circa A.D. 580).

In the same era as the 395–402 earthquake, Philostorgius (A.D. 425), who was almost certainly referring to an event in Constantinople, wrote, "Earthquakes commenced which cannot be easily compared with those that have taken place before. Together with the earthquakes, fire bursting forth and falling from the sky cut off all hope of safety. Yet it did not work any destruction on mankind. For divine grace sent down a violent wind and drove the fire around every which way, and the fire departed down to the sea. Then there was a strange spectacle to behold: The waves over a very great distance [or, for a very long time], as in the case of certain wooded areas [or, as well as certain maritime districts], burned up with fire until finally the flame was extinguished in the sea." Nicephorus Callistus (14th century) places the event in the reign of Arcadius (395–408), which suggests that it is the same event that Augustine described. Photius (9th century), however, states that it occurred in the year after the total solar eclipse of 19 July 418 (Schove, 1984). The nature of the sky fire is ambiguous here. Although the flame may well have been earthquake lights, especially if it refers to the 395–402 event, it could also have been fiery wind-swept debris ripped off from burning city structures.

CONCLUSION

Of twelve possible cases of earthquake lights considered here for the period before A.D. 600, there appears to be one case (A.D. 395–402) that is virtually certain, along with another (A.D. 419?) that is either the same case but misdated, or is at least quite probable. Most of these cases are concentrated in space and time in or around 4th- and 5th-century Constantinople, a circumstance mainly due to the vagaries of historical reporting.

The one nearly certain case of earthquake lights comes from Constantinople, and all the circumstances surrounding it resemble the reported phenomena of the 1999 Izmit (Kocaeli) earthquake. Fires at damaged area oil refineries in 1999 (Barka, 1999; Gore, 2000), however, produced a powerful sulfur odor that could have masked the smell of any nonanthropogenic source of sulfur from the fault break if there was any such escape of gases. The earthquake lights may have been due to the burning of released natural gases in both instances. Although electrical discharges in the air are another potential cause, the two possibilities are not mutually exclusive, since a discharge could have ignited the gas or caused it to glow. In any event, the present work suggests that earthquake lights have been an occasional accompaniment of large earthquakes in the Sea of Marmara area for at least sixteen centuries.

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