THE MAY - JULY 1978 EARTHQUAKE SEQUENCE NEAR THESSALONIKI GREECE

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By

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Comment

This paper, prepared as a preliminary report shortly after the 1978 Greece earthquake sequence, was partially incorporated in the Earthquake Engineering Research Institute's reconnaissance report, "Thessaloniki, Greece Earthquake, June 20, 1978."

Introduction

On June 20, 1978, a magnitude 6.5 earthquake occurred in an agricultural valley between Lakes Langadha and Volvi, (see Figure 1) 30 km east of the major Macedonian port of Thessaloniki (also called Salonika). The death toll approached 50, with 38 fatalities resulting from the collapse of a single apartment building in Thessaloniki. A team of U.S. Geological Survey (USGS) geologists and seismologists (Maley, Bufe, and Yerkes) were dispatched to the scene, arriving on June 27 after consulting with Dr. John Drakopoulos from the National Seismological Observatory, Dr. Panayotis Carydis from the National Technical University of Athens, and officials at the U.S. Embassy in Athens on the 26th. Diplomatic and logistic support in Thessaloniki was provided by the U.S. Consulate General, Mr. Dan Zachary, and by Consul Carl Sharek of the American Center. On June 28, at a meeting with Professor Papazachos, seismologist at the University of Thessaloniki, and Mr. M. Martis, Minister of Northern Greece, an army helicopter reconnaissance flight was scheduled over the epicentral region. Visible ground rupture was evident in the vicinity of the towns of Stivos and Skolari. A stop was made at Skolari to install a digital event recorder. On June 29, Yerkes, Bufe, and a guide-interpreter (Nicos Papaconstantinou) provided by the consulate, began mapping the surface rupture and gathering pertinent information from local sources. Maley investigated damage effects and consulted with Greek engineers.

After completing their brief investigation of the earthquake, the initial USGS team left Greece on July 5. On their return trip, Maley and Bufe visited with Professor Galanopoulos in Athens. Between July 3 and 22, David Carver and Ron Henrisey of the USGS operated a 10-station network of smoked paper seismographs in the epicentral region.

Ground Rupture

The region of mapped ground rupture occurred in the area between Lakes Langadha and Volvi where the trend of the valley changes from east-west to northwesterly. The surrounding region has experienced moderate to large earthquakes in 1902, 1904, 1905, 1931, 1932, 1952, 1958, 1960, and 1978. On the basis of felt reports, the 1902 and 1978 events were very similar. Ground rupture mapped in the valley between Lakes Langadha and Volvi falls into two patterns, shown in Figure 1.

1. A zone of discontinuous, step-to-the right ruptures along a west-northwestly trend, passing through the towns of Stivos (Figure 2) and Skolari. Numerous ejection craters and fissures (example in Figure 3) were observed in the dry river bottom south of Skolari.

2. An east-west trending zone of open ruptures along the south side of the valley with north-side-down scarps passing through the towns of Yerakarou (Figure 4), Nikomidhinon, and Stivos. Maximum observed displacement was 30 cm vertical, with a 10 cm tensional opening on a rupture east of Yerakarou. Some of the observed displacement may have resulted from slope failure; however, the zone occurs along the base of a probable fault-line scarp off-setting the flood plain by approximately 3 m. The northwest-trending 1978 ruptures and many of the 1978 and earlier earthquakes occurred along the northwest-trending faulted boundary between the Rhodope (Serbo-Macedonian) massif of crystalline and metamorphic rocks on the north and intensely deformed Mesozoic metasedimentary rocks of the Vardar "root" zone on the south.

Other Observations

The 1978 sequence began with a swarm of events on May 8-10, followed by a magnitude 5.8 foreshock on May 23. The main shock occurred on June 20, and was preceded by foreshocks (largest magnitude 5.0) on the 19th. The largest aftershock to date (magnitude 5.0) occurred on July 4. This fortnightly pattern of occurrence is suggestive of tidal triggering, but no significant surge of activity was observed on July 18-20.

Many interesting observations of various phenomena before and after the main shock were made by the local residents. Residents of Skolari reported a stream of very hot air escaping early in the morning of June 21 from a fissure (Figure 5) where the fault crosses a macadam road. On the delta south of Lake Volvi fountaining of hot water was reported from a zone of fissures. Residents reported that from the beginning of the foreshock sequence on May 8 until the time of the June 20 shock the earth was "boiling". The epicentral area lies between hot springs located north of Lake Langadha and at the southern edge of Lake Volvi (Figure 1). Dogs howled and cattle were restless. Water in wells turned cloudy 2 to 12 hours before the main shock.

General Effect on Thessaloniki

Many residents left Thessaloniki immediately after the mainshock causing severe traffic congestion and numerous serious accidents while a large part of the remaining population began to erect "tent cities" in any available space (Figure 6). In response to this, the Greek army distributed 60,000 large tents to residents who had need for them. Army personnel also prepared sanitary facilities at the sites of large tent concentrations. Because of continuing aftershocks and fearing the occurrence of another and even stronger earthquake, only a limited number of residents had elected to return to their homes by late July, despite the fact that many of them lived in structures that had been inspected and were considered safe for occupancy. This feeling may have been strengthened by the sequence of events that occurred between the May 23 and 24 magnitude 5.8 and 5.1 foreshocks and June 20. Following the May earthquakes, a nervous populace was given the impression from government authorities that the earthquake series was probably over, based on the best of information available. Apparently the public was adequately convinced there would not be further earthquakes and consequently the activity in Thessaloniki returned to normal. After the magnitude 6.5 June 20 earthquake, the populace remained steadfast in their belief that an even stronger earthquake could occur in the future. Since previous seismicity patterns in northern Greece show a series of large earthquakes over several years, 1902 to 1905 and 1931 to 1933; the population in general was yet not ready to return to their residences, at least not within in the first five weeks after the main shock.

Following the earthquake, 100 two-man inspection teams were sent into the field to assess the relative safety of all buildings in Thessaloniki. These teams then posted the entrances with large colored stickers indicating the conditions of occupancy: green, the structure was safe and could be used for normal living or business purposes; yellow, the building required repairs and could not be occupied although tenants could re-enter temporarily to gather up their belongings; and red, entry was prohibited until the structure had been repaired. By July 7, 30,000 dwellings had been inspected with 9% of these receiving red stickers. The yellow and red stickered buildings were causing considerable hardship, particularly for businesses and owners of the buildings. One of the serious problems facing Greek authorities was how to accomodate, in new or temporary housing, the 40,000 dislocated Thessalonians until reconstruction of their present housing can be completed. According to the local press, there were some large upward revisions of rents at many of the buildings that were judged to be in satisfactory condition.

Instrumental Data

During the early aftershock sequence the only local seismographs were a smoked paper portable seismograph operated by the University of Thessaloniki and a strong-motion accelerograph in Thessaloniki. Professor Papazachos installed the portable seismograph at Skolari, but the record was swamped with small local earthquakes. After a few days the instrument was moved to Thessaloniki where S-P intervals indicated most of the aftershocks were about 30 km from the city. On June 28-29, magnitude 4 events with shorter S-P intervals were felt in Thessaloniki, raising fears that the aftershocks were migrating toward the city or that a new foreshock sequence had begun. From felt reports and relative epicenters from the Greek regional network, it appeared that the sequence had progressed from east to west, toward Thessaloniki. A request was made to USGS headquarters for additional recorders to permit accurate location of the earthquakes. On July 1 Dave Carver and Ron Henrisey left Golden, Colorado with 10 smoked paper seismographs, arriving in Thessaloniki on July 2. On July 3 the network was deployed by helicopter in the region between Thessaloniki and Lake Volvi. On the following day the largest aftershock (M = 5.0) occurred.

Preliminary aftershock locations from the local USGS network fall principally into two clusters (Figure 1), one along the north side of Lake Langadha, the other 5 km NW of Lake Volvi. Focal plane solutions for the main shock and the May 23 magnitude 5.8 foreshock obtained from Professors Galanopoulos and Papazachos and for aftershocks located under Lake Langadha using data from a 10-station USGS network of portable seismographs are consistent with left-lateral strike slip along a fault trending WNW and dipping steeply to the north (although this interpretation is not unique). Inferred principal stress orientations are east-west compression and north-south extension, similar to those for the 1963 Skopje, Yugoslavia earthquake.

A report on the earthquake was prepared, at the request of the Greek government, by Ota Kulhanek and Klaus Meyer of the Seismological

Observatory, Uppsala, Sweden. They propose, on the basis of its seismic signature at Uppsala, that the June 20 event was a double shock, small and large, separated by 2.5 seconds.

An accelerogram recorded by an instrument operated by the National Observatory of Athens in Thessaloniki suggests the June 20 event was a complex rupture consisting of two or more events (Figure 7). The record is characterizied by two distinct sections of higher amplitude motion, one beginning 3.3 seconds after the instrument triggered and other approximately 4.5 seconds later.

The accelerograph was installed in the basement of an eight-story building located on "relatively poor alluvial soils" a few hundred meters from the Gulf of Thessaloniki: it recorded the following maximum accelerations:

Azimuth	Acceleration (g)
150°	0.14
up	0.13
60°	0.15

Each component had 4 to 5 peak amplitudes equal to or exceeding 0.1 g occurring over an interval of 0.6 to 1.2 seconds.

The S-wave minus triggering (S-t) interval is approximately 3.3 seconds. Assuming a triggering delay after initial P-wave arrival of no more than 0.1 to 0.2 seconds, the S-t interval is consistent with a seismic source at 25 to 30 km distance.

A high quality photographic record copy, recently transmitted to the USGS by Professor J. Drakopoulos has been digitized prior to calculation of corrected acceleration, velocity and displacement curves, and various response and response duration spectra.

The magnitude 5.8 foreshock on May 23 was not recorded by the accelerograph at Thessaloniki although a number of aftershocks following the June 20 event triggered the instrument. These records were minor with the exception of that from the magnitude 5.0 July 5 shock where there were a few seconds of significant motion. The S-t interval was 2 seconds indicating the earthquake occurred at 15 to 20 km distance, considerably nearer to Thessaloniki than the main shock.

Shortly after the earthquake, an investigation team from the Institute of Earthquake Engineering and Engineering Seismology, Skopje, Yugoslavia, installed three accelerographs in Greece; one at Skolari in the epicentral area, and two in Thessaloniki, the first on rock and the second near the location of the eight-story building collapse. Aftershock results from this network are not yet available.

Damage Effects and Casualties

Damage from the mainshock was concentrated in Thessaloniki, the largest city in northern Greece, as well as a number of small villages situated in the valley area between Lakes Langadha and Volvi. Approximately 50 people died as a result of the earthquake; 38 in the collapse of an eight-story reinforced concrete building in Thessaloniki, six as a result of traffic accidents (post-earthquake exodus) and heart attacks, and the remainder in isolated incidents. Although numerous unreinforced masonry structures suffered total collapse, particularly in the villages, the casulty toll was not large due to the occurrence of foreshocks about nine hours before the earthquake. As a consequence, most people had evacuated their residences and were on open ground at eleven in the evening when the earthquake struck. Had this forewarning not been present, many more casulaties could have been expected from building failures and from falling parapets, overhangs and facades that damaged hundreds of buildings in Thessaloniki.

Thessaloniki

Significant structural damage was limited to but a few buildings in Thessaloniki; most notably the eight-story building collapse, severe column damage on the ground floor of a nearby eight-story building, and column damage to a two-story police station under construction at the airport. The two eight-story buildings were located in a small area of the city that was most heavily damaged and includes old unreinforced or poorly reinforced government buildings that have been or will be demolished. Engineers from the Ministry of Public Works report the soil conditions in this area are unusual since some of the present structures have been built over and upon old brick ruins that have sunk well below the present ground surface. Presumably the area was brought up to grade by landfill many years ago. The high level of damage in this area compared to the relatively undamaged remainder of the city suggests possible local amplification of strong shaking.

The collapsed eight-story reinforced concrete building that caused a majority of the fatalitites during the earthquake, was cleared away by the time the USGS team arrived. During the collapse the building or part of it apparently fell against an adjoining building tearing out a section of the exterior wall and knocking down several balconies (Figure 8). Considering the unusual soil conditions in this area of the city, a contributary factor could be an anomalously high ground response at the site. Perhaps records from a Yugoslavian accelerograph installed approximately 50 m from the collapse, will shed some light on this possible effect, particularly if there is data from the July 4 aftershock.

A second eight-story reinforced concrete building located two and one-half blocks from the collapse site, had badly damaged ground floor columns (Figure 9). The corner columns were intact while the interior frontal columns suffered failures near grade and at 1-1/2 to 2 m heights (Figure 10). Engineers from the Ministry of Public Works (MPW) reported the structure was leaning 5 cm toward the street. The building has forty owners, similar to western condominiums, and since they could not be located in a short period of time, the MPW was considering shoring up the building to prevent possible collapse during another strong earthquake.

A two-story reinforced concrete police station under construction 300 m from the airport terminal suffered column damage and failure of tile walls on the ground floor (Figure 11). The second floor was not damaged. The building is square, approximately 20 m on a side, and has twelve equally spaced square perimeter columns, 50 cm wide and 5 m high. There are no shear walls in the structure although a vertical reinforced concrete element supporting the stairs may have provided some lateral resistance. This is suggested by less serious column damage on the stairway side of the building. There is a small interior steel frame along the back of the building and the sides. Its purpose is unknown. The columns were damaged within the first 80 cm above the floor and near the tops of the columns (Figure 12). In every instance the upper damage occurred at the pour joints (Figure 13). There was no evident distress at the column beam connections.

Many of the old structures in Thessaloniki, particularly churches, suffered considerable damage. The Metropole church, which was rebuilt after a fire in 1917, showed widespread cracking and will have to be reinforced before it can be safely occupied. Army troops installed log shoring in Saint Sofias church pending repair of the structure. The spire next to the Rotunda, which has suffered a gradual attrition over hundreds of years, lost more bricks near the top. Some bricks also fell off of the Arch of Galerius.

Non-structural damage, though wide-spread throughout Thessaloniki, was concentrated in the older more ornate buildings. Typical external damages consisted of fallen parapets, cornices and overhangs, plaster spalling from hollow tile walls (Figure 14), fallen ornamental brick-work, marble facades that separated and dropped off walls, and spalling between adjacent buildings that were constructed with no separation. In one instance, decorative hollow concrete blocks used as facade for an exterior stairway collapsed both inward on the stairs and outward on the street and sidewalk (Figure 15). An ornamental brick arch fell along Aristotle Plaza (Figure 16). A nearby column lost its brick covering (the column was undamaged). A church located near the eight-story collapse was undamaged, but all exterior panels separating adjacent windows had fallen off.

According to Greek authorities, the July 4 aftershock killed one person and caused additional damage to numerous structures in Thessaloniki, including the collapse of a three-story apartment building.

Langadhas

Langadhas, the largest city in the epicentral area, is located northwest of Lake Langadha, approximately 20 km from the instrumentally located epicenter and 15 to 25 km from the fault zone in the central section of the valley. Buildings in the city generally suffered little or no damage. A six-story reinforced concrete building with hollow tile walls was structurally sound, although the wall on the ground floor was badly wracked and required exterior shoring to prevent it from toppling to the street. A one-story tile factory near Langadhas was constructed with a lower reinforced concrete wall about 3 m high with narrow reinforced concrete columns joining the top of the wall to support the roof about 3 m higher than the wall. During the earthquake, the columns on one side of the building fractured at the base and leaned a few degrees towards the center of the structure; columns on the opposite side of the building were unaffected. Some nearby one-story unreinforced concrete block farm buildings were damaged, although no instances of complete collapse of these structure were observed.

Kolhikon and Analipsis

Little damage was noted in these villages except to some small unreinforced concrete block buildings and hollow tile walls in other structures. Near Analipsis a one story shirt factory with unreinforced hollow tile walls that supported the roof was badly damaged; the hollow walls were replaced by wood shoring after the earthquake.

Skolari

The fault zone passed directly through Skolari rupturing a concrete slab in a garage, cutting through the main road in town, and extending beneath a house that was damaged but did not collapse (Figure 17). Numerous unreinforced mud brick and concrete block farm buildings suffered total collapse (Figure 18). Much of the damage in Skolari was clearly traceable to the existence of faulting passing through or near buildings. The newly built church, location of a Yugoslavian aftershock accelerograph, was undamaged.

Yerakarou

Ground rupturing passed through Yerakarou severely damaging several buildings, most notably several residental structures in the path of the fault zone. The damage included a two-story house constructed with a ground floor of reinforced concrete columns and beams joined to walls that were a mixture of concrete blocks and cemented rocks (Figure 19). The first level of the building was undamaged except for some holes in the wooden ceiling caused by fallen debris (Figure 20). The second floor, which appeared to have been constructed at a later date, consisted of unreinforced brick and hollow tile. The second floor was severely damaged; both exterior walls were near collapse and the interior tile walls toppled on to the bed, couch, table and floor (Figure 21). Fortunately, the building had been evacuated when the foreshocks occurred, that is with the exception of the mother-in-law who survived the earthquake while sleeping on the ground floor. Some residences located away from the fault zone had badly cracked tile walls and could not be safely occupied (Figure 22).

Stivos

Faulting crossed the highway northwest of Stivos passing with 10 to 20 m of a two-story reinforced concrete bulding under construction for the office and residence of a FINA service station (Figure 23). The structure is approximately square with nine irregularly spaced 17 cm square perimeter columns, four at the front and three on the sides. Several columns were damaged at the base, just below the mezzanine level

(Figure 24), and near the second floor; the latter were those that did not intercept the mezzanine extending across half the building area. The most heavily damaged west side of the structure had no wall up to the second floor (providing entrance to the vehicle servicing area), whereas the solid east wall of the building suffered no damage (Figure 25), except to the base of the corner column. The station operator reported the existence of faulting during the 1932 earthquake, but in a different location than that of the 1978 shock.

The fault zone passed through Stivos interceped the main road and ran directly through at least one structure that partially collapsed (Figure 26). Several unreinforced concrete block, stone, and mud brick buildings were severely damaged or shaken down. A three-story reinforced -concrete frame building in central Stivos had ground floor damage consisting of damage to column bases and at the column-beam connections.

Peristerona

Peristerona is a small village located on a steep slope two kilometers southwest of Lake Volvi. On the hill just above Peristerona there were a few streches of linear fissures several hundred meters in length that appeared to be a secondary faulting phenomena, such as slumping or sliding. Residents report that these fissures appeared during the May foreshocks and were enlarged by the June 20 earthquake.

In constrast to other areas, the damage pattern in this village seems to bear no relationship to the location of the fracture zone since the structures in the upper reaches of Peristerona were essentially intact. But at the base of the hill, just above the intersection of the slope and highway, a number of houses and the entrance to the church were severely damaged (Figure 27). The church had a bell tower with a concrete cupola shaped dome supported by four narrow reinforced concrete columns standing over the walkway immediately in front of the main doors. The bell tower collapsed, although the remainder of the church was in good condition (Figure 28). Several unreinforced concrete block farm structures in the valley northwest of Peristerona were also flattened.

Further east, between Peristerona and Nea Apollonia, cracking was observed in the highway where it had been constructed on earthfill crossing a small valley. This cracking, undoubtedly due to subsidence, was originally observed after the May foreshocks, but it had increased during the June 20 earthquake. One of the two concrete lined tunnels that passed under the roadway at about 6 m depth had new cracks with a few mm displacement in both vertical and horizontal directions.

Acknowledgements

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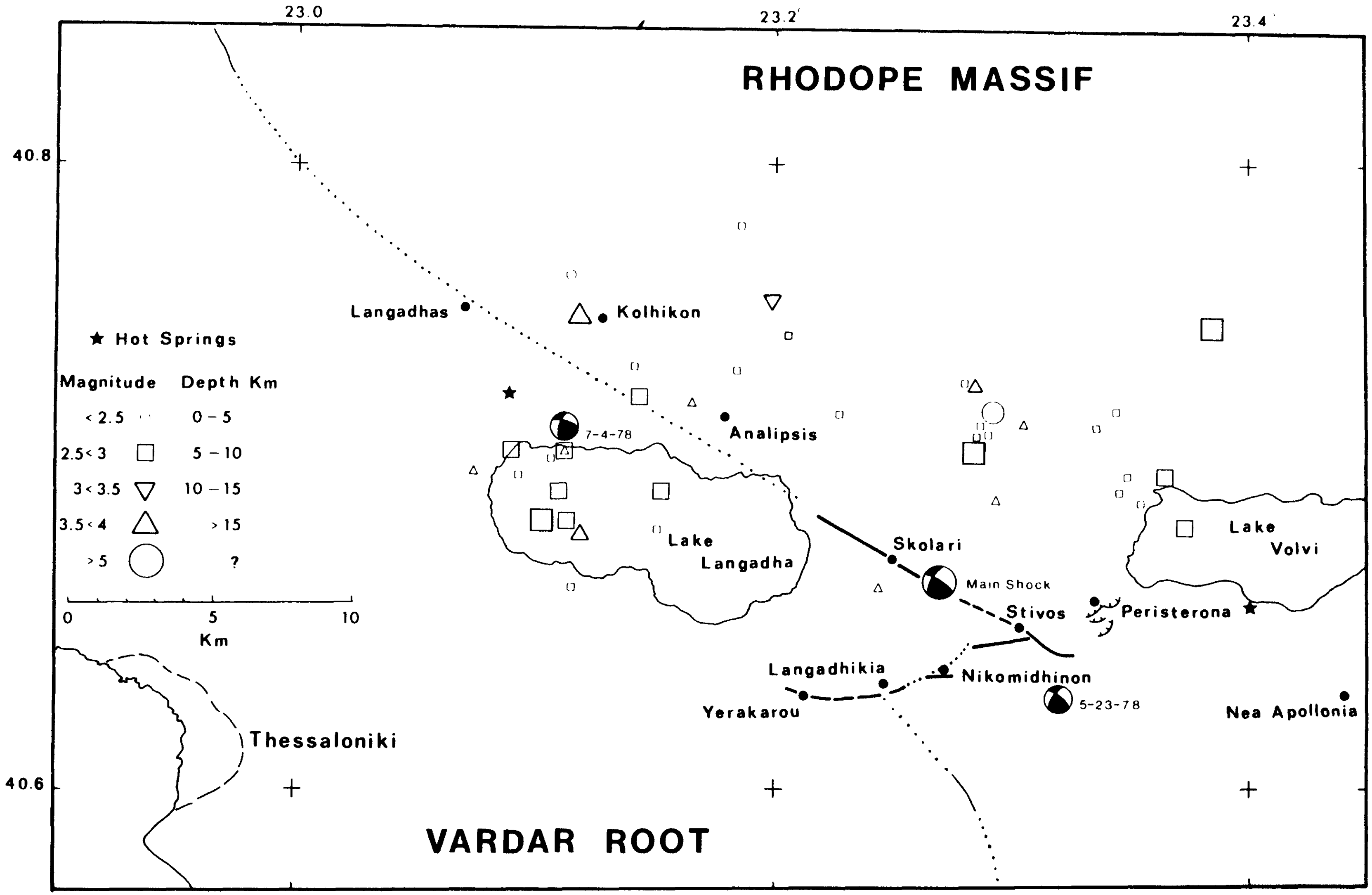

Figure 1. Map of Langadha-Volvi Lakes area showing 1978 ruptures (heavy lines), faulted boundary between the Rhodope massif and the Vardar root zone, and selected epicenters of the 1978 earthquake sequence. Fault diagrams are lower hemisphere with the compressional quadrants dark.

Figure 2. Ground rupture through the soccer field at Stivos, looking eastward.

Figure 3. Ejection craters in the riverbed along a WNW trend of ground rupture southeast of Skolari.

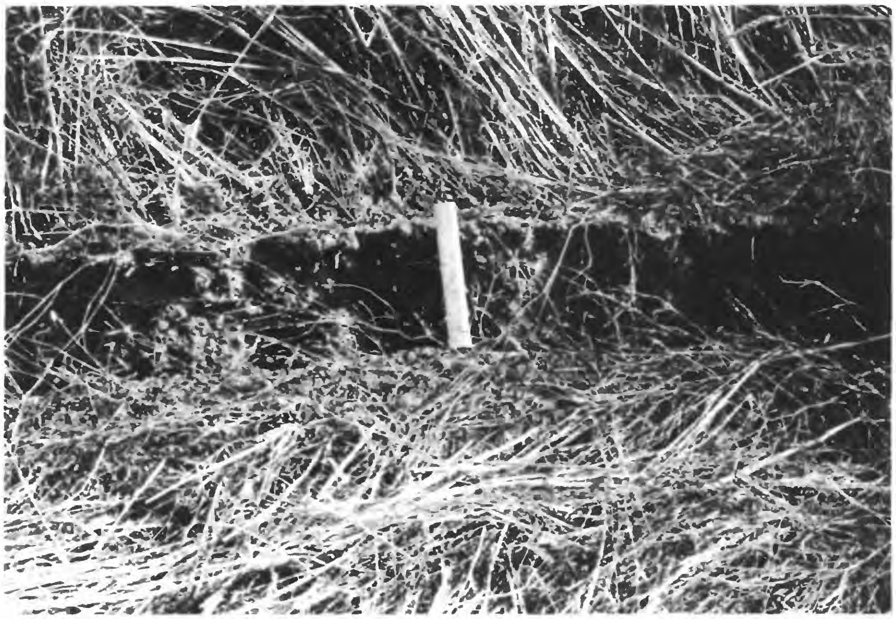

Figure 4. View of the scarp at Yerakarou, looking south. The scale is 30 cm long.

Figure 5. Ground rupture crossing a macadam road in Skolari where townspeople reported a stream of hot air venting through the cool pavement on the morning of July 21, about 8 hours after the main shock.

Figure 6. Tents erected for temporary housing in a Thessaloniki park.

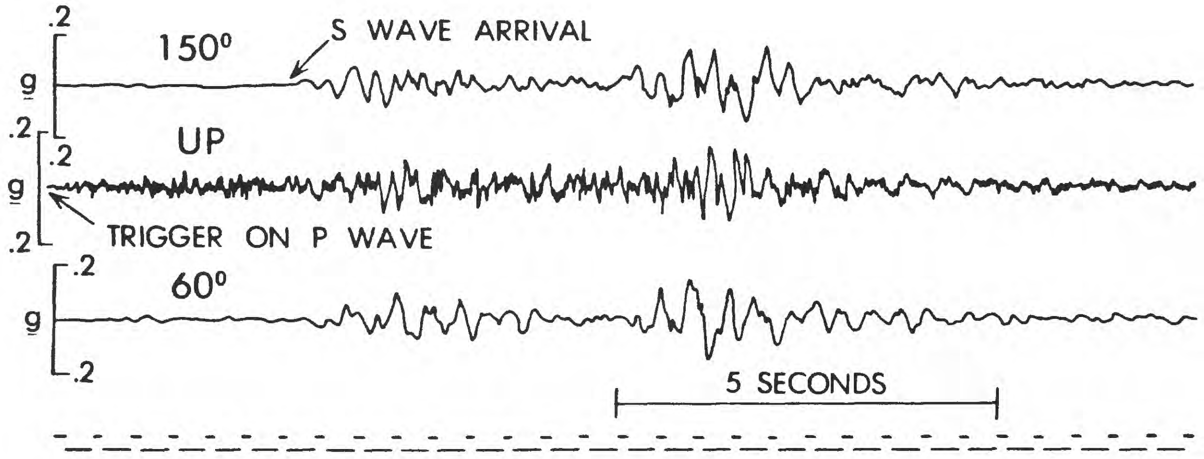

Figure 7. Tracing of the Thessaloniki accelerogram.

Figure 8. External damage to an eight-story building caused by the collapse of an adjacent structure.

Figure 9. An eight-story reinforced concrete building with first-floor column damage.

Figure 10. Column damage on the first floor of the eight-story reinforced concrete building shown in Figure 9.

Figure 11. A two-story reinforced concrete police station under construction near the Thessaloniki airport.

Figure 12. Damage near the base of a column at the police station.

Figure 13. Damage at a column pour joint at the police station (Figure 11).

Figure 14. Spalled exterior plaster on a medium rise building in Thessaloniki.

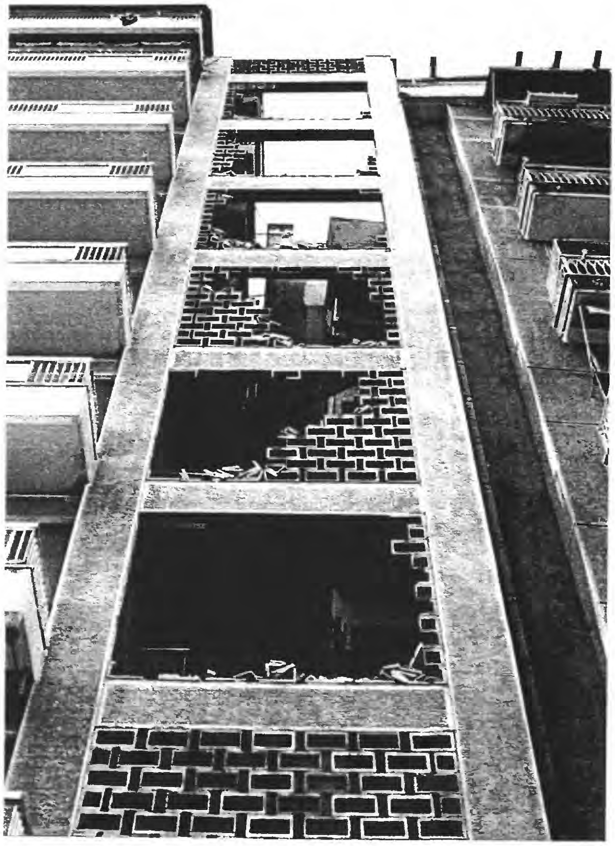

Figure 15. Collapse of a hollow-tile facade between two buildings in Thessaloniki.

Figure 16. Unreinforced brick arch collaped on Aritstotle Plaza in Thessaloniki. Newer buildings on the same street have reinforced concrete arches.

Figure 17. Fault zone passing through a house in Skolari.

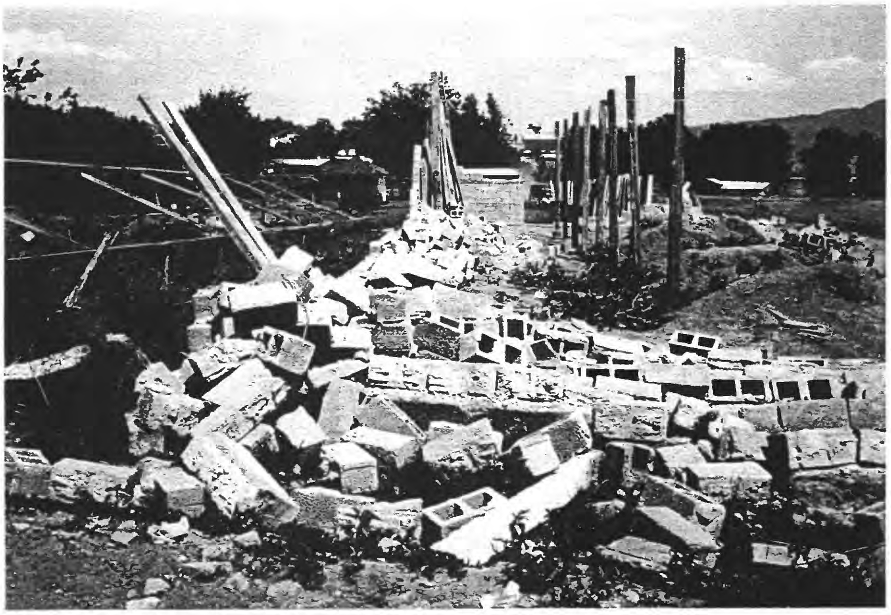

Figure 18. Collapse of an unreinforced concrete block farm building near Skolari.

Figure 19. The rupture zone passed through this house in Yerakarou. The building has a reinforced concrete first floor and a tile wall second floor.

Figure 20. Tile partition fell upon a table on the second floor driving the legs through the first floor ceiling. House in Figure 19

Figure 21. Hollow tile collapsed onto the couch on the second floor of the house shown in Figure 19.

Figure 22. A badly damaged residence in Yerakarou.

Figure 23. A FINA service station under construction near Stivos. The fault zone is located between the tent, now occupied by the residents, and the building.

Figure 24. A damaged column at the FINA service station (Figure 23).

Figure 25. The undamaged rear wall at the FINA service station.

Figure 26. Faulting passed through a concrete block building in Stivos demolishing the down-slope section of the structure.

Figure 27. Typical damage at Peristerona near the base of the hill.

Figure 28. Collapsed entranceway columns at the church in Peristerona.