BACKGROUND

From the Geological Survey of Alabama
http://www.gsa.state.al.us/gsa/geologichazards/earthquakes/ftpayne.html (June 9, 2004)

> Tuesday morning, April 29, 2003, at 3:59 A.M., a strong earthquake with a magnitude of 4.9 md occurred in DeKalb County, Alabama, just east of DeSoto State Park and 10 miles ENE of Fort Payne, Alabama. Pictures moved on walls, items fell off shelves, a trailer was shaken off its foundation. Many people were shaken out of their beds when the thunderous rumble and then a strong shake of the ground began. Some reported the trembling lasted less than 10 seconds, while some areas reported shaking up to 45 seconds.
>
> This earthquake is not an isolated event. [A similar event occurred 2 years earlier, in the same area.] It is the largest earthquake in the largest and second most active seismic zone in the eastern United States, the East Tennessee Seismic Zone.

When the Earth's crust ruptures, a tremendous amount of elastic energy is released. This energy is transmitted through the Earth as seismic waves. There are two general types of seismic waves, **surface waves** and **body waves** (Figure 1). An earthquake is experienced when the passage of surface waves causes the ground to shake noticeably, sometimes violently.

Body waves travel through the interior of the Earth and are divided into 2 types, ***P*** (primary) waves and ***S*** (secondary) waves. Because *P* waves travel nearly 2 times faster than *S* waves, *P* waves are always ahead of *S* waves. The farther the 2 waves travel, the further ahead the *P* wave becomes. Consequently, the delay between arrivals of *P* and *S* waves at a seismic station (Δt_{sp}) relates to the distance that the waves have travelled. This relationship is shown in Figure 2.

Figure 1. Simplified model of Earth (core, mantle, crust) showing paths of seismic waves. Note that the time delay between arrivals of P and S waves (Δt_{sp}) is greater for the seismic station that is farther from the earthquake source (station 2).

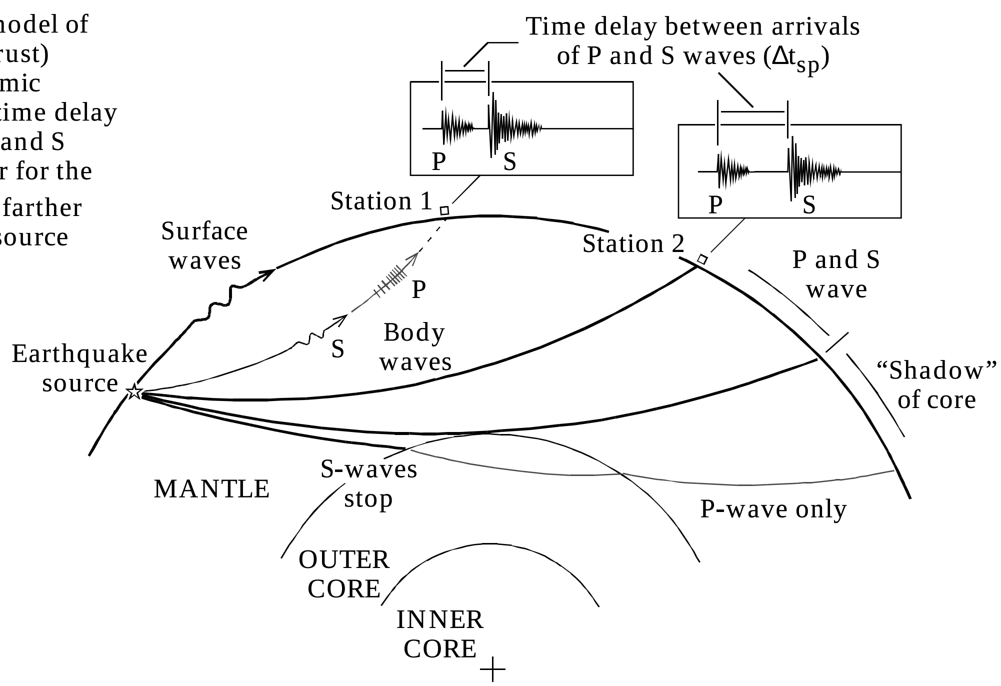
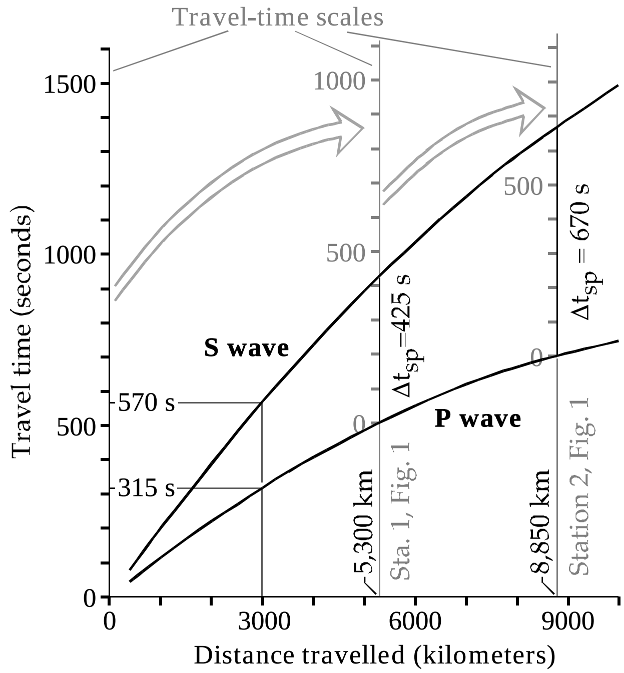


Figure 2. Traditional plot of travel time versus distance travelled for P and S waves. As shown by this graph, for example, a P wave travels 3,000 km in 315 seconds, while an S wave takes 570 seconds to travel the same distance.

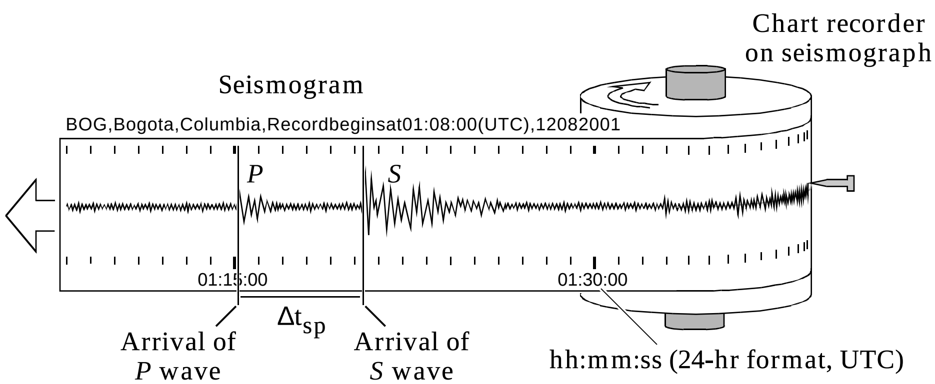
This graph is commonly used to determine the distance to an earthquake's source from the delay between arrivals of P and S waves (Δt_{sp}). If, for example, Δt_{sp} = 425 seconds for station 1 in Figure 1, the distance to the source is 5,300 km. This is the distance indicated on the x axis of the graph at which the gap between the travel-time curves equals 425 seconds by the travel-time scale on the y axis of the graph. If Δt_{sp} = 670 seconds for station 2 in Figure 1, the distance to the source from station 2 is 8,850 km.

The travel time axis can be transferred to to various points along the distance axis using a separate sheet of paper.



Every seismic station is equiped with at least one **seismograph**, the instrument used to measure seismic waves. The seismograph produces a **seismogram**, which is a record of time and seismic-wave amplitude (Figure 3). On the conventional seismogram, time advances from left to right.

Figure 3. The seismogram and its relation to the seismograph's chart recorder. Arrivals of the *P* wave (01:15:05) and the *S* wave (01:20:20) are shown, as is Δt_{sp} (315 s). Note that, on this seismogram, small ticks mark 1-minute (60-second) intervals.



UTC (Universal Time Coordinated), noted on the seismogram, is essentially the same as Greenwich Mean Time (GMT), the time of day in Greenwich, England, which lies on the prime meridian. Eastern Standard Time (EST) equals UTC (or GMT) minus 5 hours; Central Standard Time (CST) equals UTC (or GMT) minus 6 hours.

The first (primary) seismic wave on the seismogram, reading it from left to right, is the *P* wave. The second (secondary) seismic wave is the *S* wave. The arrival of each wave is noted as the first (earliest) disturbance. Commonly, each wave starts with relatively high amplitude and diminishes thereafter. Also, the *S* wave commonly has a somewhat larger amplitude than the *P* wave.

The location of an earthquake's source is described in terms of its **epicenter** and its **focus** or **focal depth**. The epicenter is the point on the Earth's surface directly above the source. The focus is the depth of the source.

DETERMINING THE LOCATION OF AN EPICENTER

To locate an earthquake's epicenter, as done in this exercise, distances from at least 3 seismic stations must be determined from the time delay between arrivals of *P* and *S* waves (Δt_{sp}). Data (seismograms) for an earthquake that occurred in northeast Alabama on December 8, 2001 are provided. The procedure described below refers to seismograms from seismic stations in the region (Figure 4). Seismograms from more distant seismic stations are provided in Figure 5. Additional seismograms for other events in the southeast and for events in other seismically active regions are also available. The procedure is as follows:

1. Study one of the seismograms provided. For example, start with the seismogram for ATL (Figure 4). Note the divisions on the time scale and what they represent. In Figure 4, major ticks are 10 seconds, minor ticks are 2 seconds. Other seismograms may be different. Mark and label the arrival of the *P* wave and the arrival of the *S* wave. Determine and record the time interval, in seconds, between the 2 arrivals (Δt_{SP}). This is most easily done by counting the interval on the time scale. Note that it may be necessary on some seismograms to convert minutes to seconds. A table for recording this information is provided (Table 1).
2. Refer to the appropriate graph of travel time versus distance travelled for *P* and *S* waves. For regionally distributed seismic stations near the source (Δt_{SP}<100 seconds), as is the case for seismograms in Figure 4, refer to Figure 6. For globally distributed seismic stations more distant from the source, refer to Figure 7. Guided by figure 2, find the point along the x (distance) axis of the graph, at which the time interval (vertical gap) between the *P*-wave and *S*-wave travel-time curves equals Δt_{SP} determined from the seismogram. This distance is the distance to the source of the seismic waves from this seismic station, ATL in our example.
3. On an appropriate map (or globe), mark the location of the seismic station. For the present example, mark the location of ATL (33.43°N latitude, 84.34°W longitude, Table 2) on Figure 8. Draw a circle on the map (or globe) such that its center is at the seismic station and its radius equals the distance to the source determined from step 2. Note that the radius of the circle must be determined from the map (or globe) scale. On a map, the circle is best drawn using a compass. On a globe, a circle can be drawn using a string. The source of the seismic waves lies somewhere along the circumference of this circle.
4. Repeat steps 1 through 3 starting with a second seismogram such that a second circle is drawn on the map (or globe). For example, repeat steps 1 through 3, using the seismogram for GLT (Figure 4). Most commonly, the 2 circles will overlap and will intersect at 2 points. If the source of the seismic waves lies somewhere along the circumferences of both circles, the source must lie at one of the 2 points of intersection.
5. Repeat steps 1 through 3 starting with a third seismogram such that a third circle is drawn on the map (or globe). For example, repeat steps 1 through 3, using the seismogram for LRAL (Figure 4). Ideally, the third circle will intersect the other 2 circles at or near one of the 2 points of intersection found from step 4. The mutual intersection of the 3 circles is the location of the epicenter.

Steps 1 through 3 can be repeated for additional seismograms for the same event.

Note that the 3 (or more) circles may not intersect at precisely the same point. In this case, the cluster of intersections is taken to be the location of the epicenter

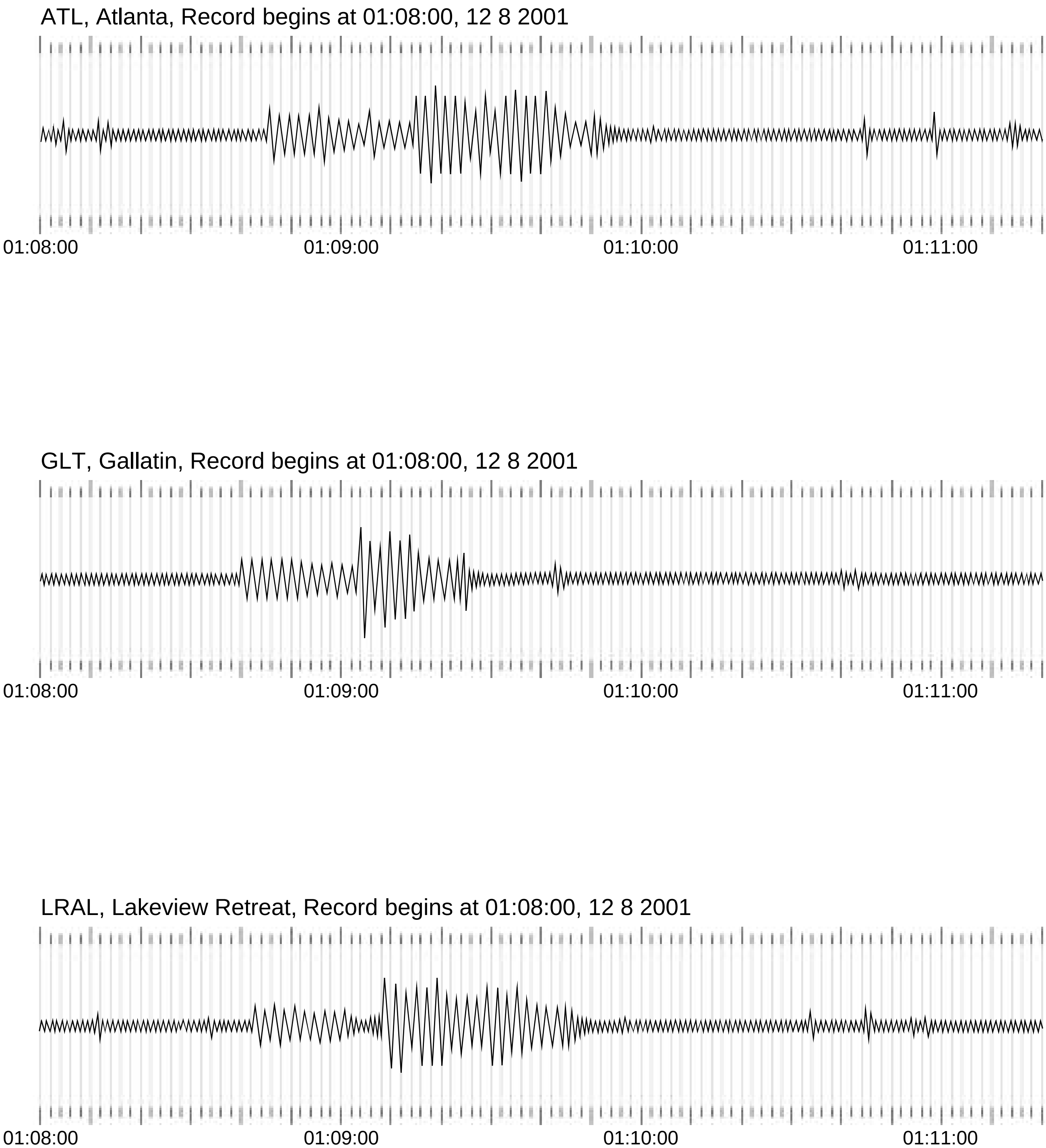


Figure 4. Seismograms from regionally distributed seismic stations for the event of December 8, 2001.

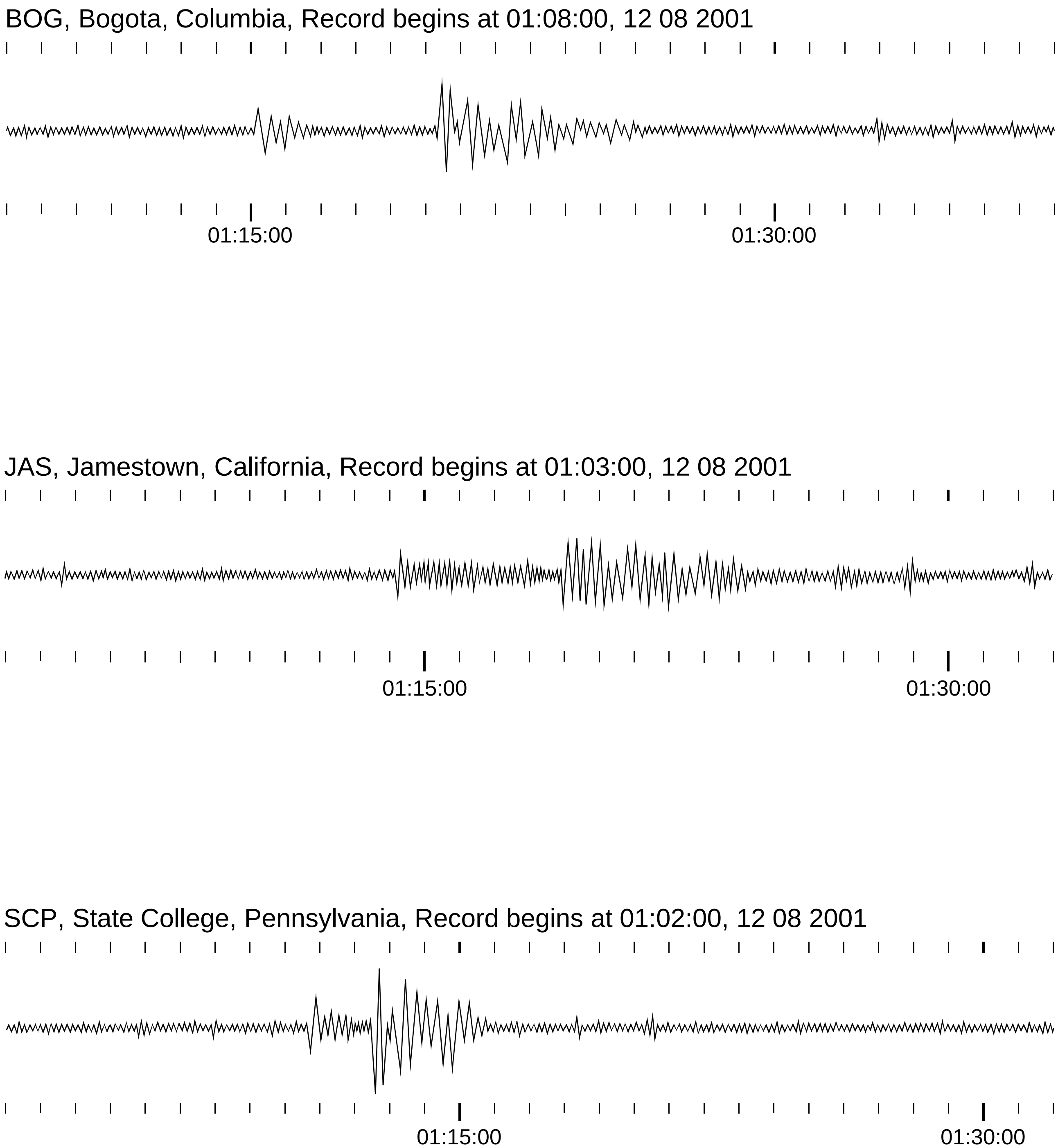


Figure 5. Seismograms from globally distributed seismic stations for an event that occurred on December 8, 2001.

Table 1. Seismic wave data and distances to source.

	Seismic Station	**Δt_{sp}** *From seismogram*	**Δt_{sp} (seconds)** *From seismogram*	**Distance (kilometers)** *From time-distance plot*
1.				
2.				
3.				
4.				
5.				
6.				

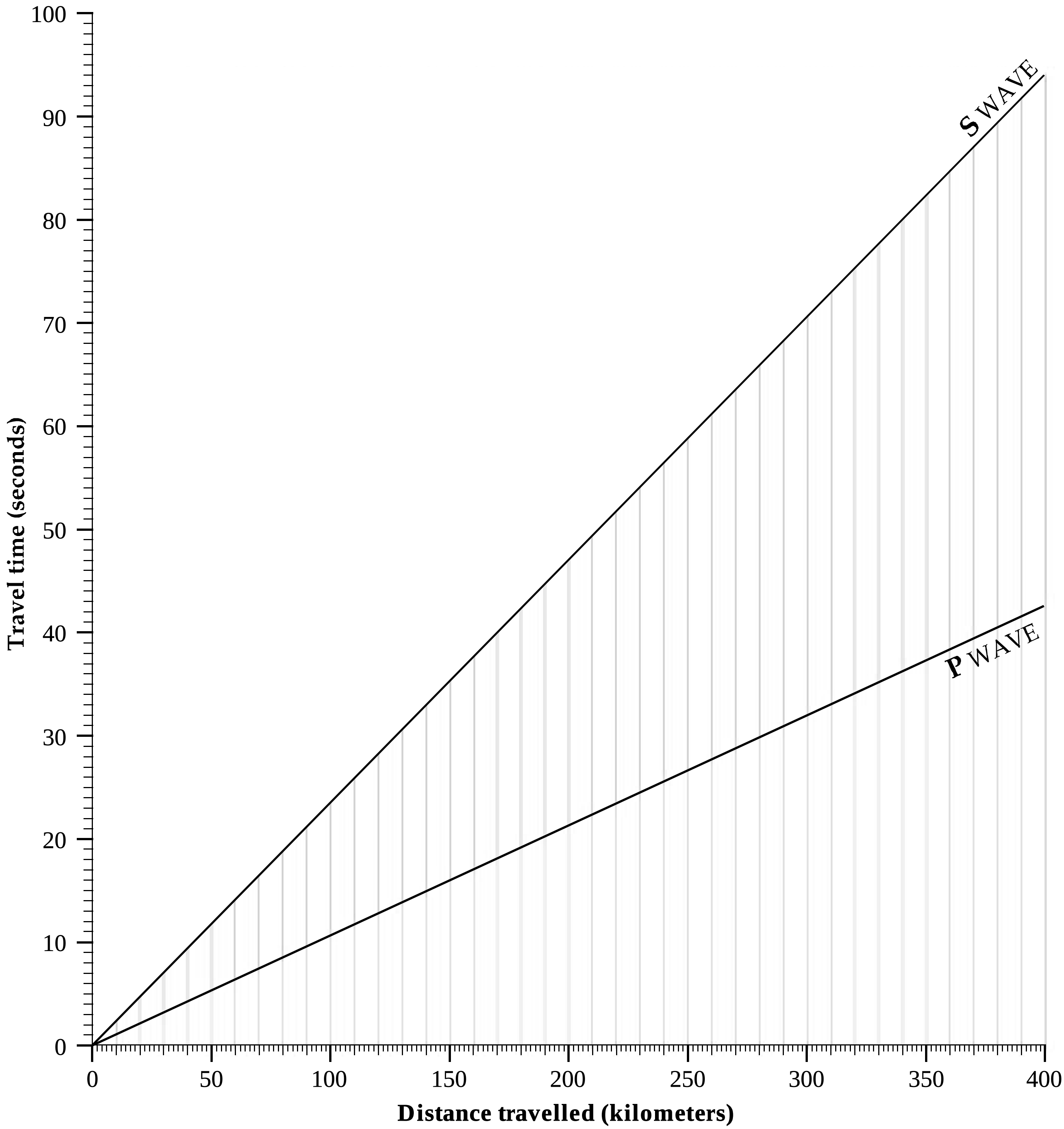
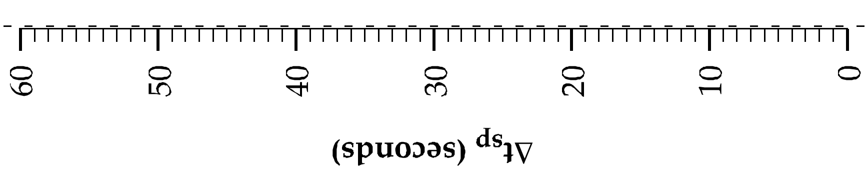


Figure 6. Travel time vs. distance travelled (0 to 400 km, on Earth's surface) for *P* and *S* seismic waves.

cut

Detach this scale and use it to determine the point along the x (distance) axis of the graph at which the time interval (vertical gap) between the travel-time curves equals Δt_{sp}.

fold



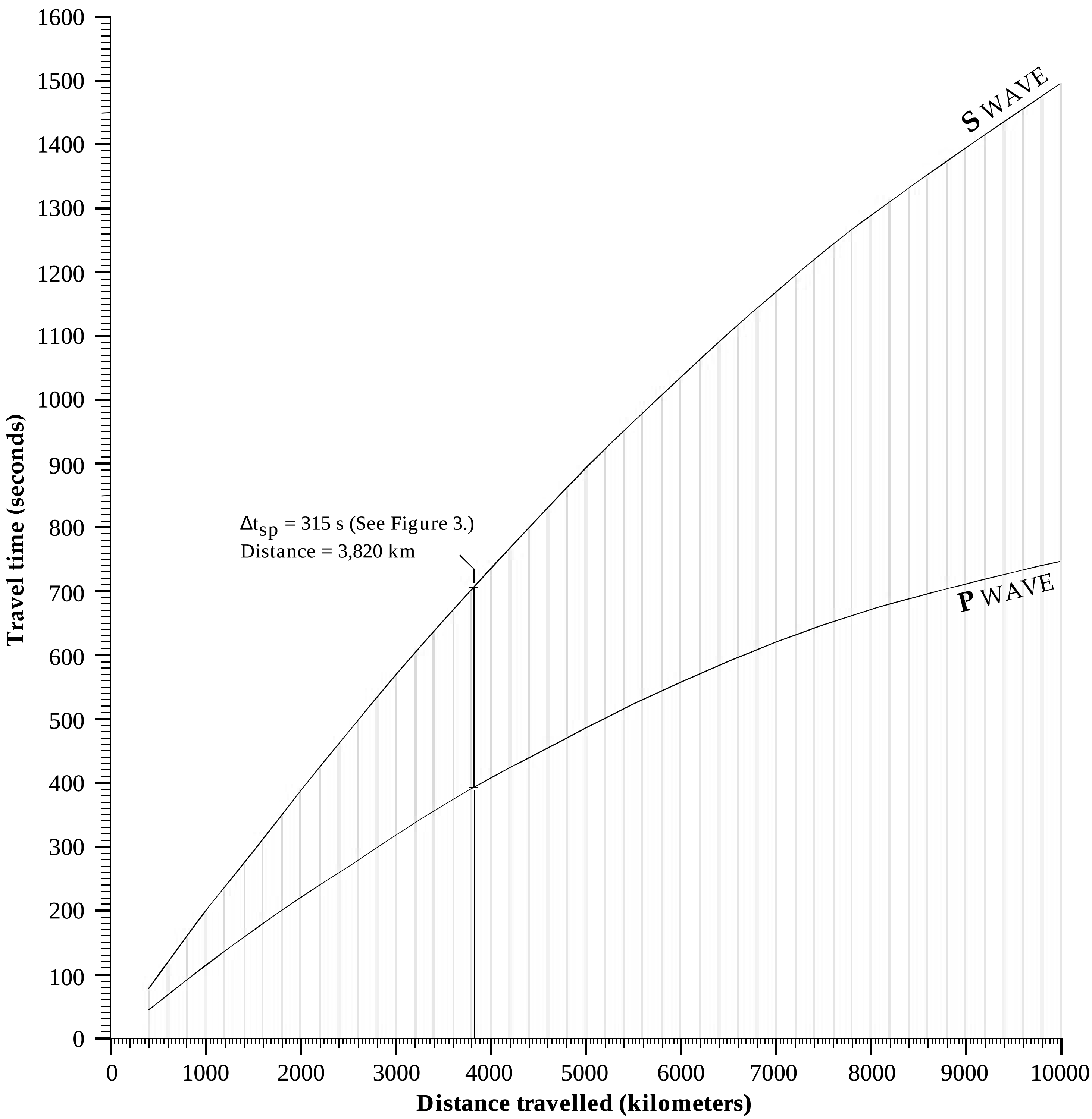


Figure 7. Travel time vs. distance travelled (400 to 10,000 km, on Earth's surface) for *P* and *S* seismic waves. The example taken from Figure 3 is shown.

cut

Detach this scale and use it to determine the point along the x (distance) axis of the graph at which the time interval (vertical gap) between the travel-time curves equals Δt_{sp}.

fold

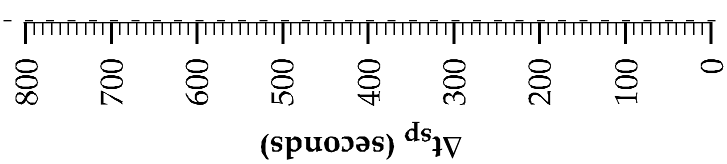


Table 2. Seismic stations in the Chattanooga (Tristate) area (83° - 87°W, 33° - 37°N). Condensed from a list available at http://wwwneic.cr.usgs.gov/neis/station_book/ .

CODE	LATITUDE	LONGITUDE	ELEVATION	NETWORK	STATUS	NAME
ABTN	35.8855	-86.109	363	TVA	Open	Auburntown
ANTN	36.1717	-85.2313	612	TVA	Open	Anderson
ATL	33.4333	-84.3375	272	ATL	Open	Atlanta
BBG	34.874	-83.811	1355	CERI	Open	BrasstownBald
BFMT	35.488	-84.227	329		Open	BirchfieldMountain
BHT	35.847	-84.945	826	CERI	Open	Blowhole
BKHT	35.532	-83.936	843		Open	Bunker Hill
BSPT	35.726	-84.109	334		Open	Big Springs
CA-TN	36.1444	-84.1897	305	LRSM	Closed	Caryville
CBT	35.5394	-84.4206	357		Open	Christianburg
CCRT	35.466	-84.054	940		Open	CowCampsRidge
CCVA	36.602	-83.667	571	CERI	Open	CudjoCaverns
CDG	34.6108	-84.6713	0	ATL	Open	Carters Dam
CGTN	36.558	-83.711	704	CERI	Closed	Cumberland Gap
CG-VA	36.6264	-83.26	396	LRSM	Closed	Cumberland Gap
COTN	35.7842	-86.9707	320	TVA	Closed	Columbia
CPCT	35.4497	-84.5218	275	CERI	Open	CooperCave
CPO	35.5948	-85.5704	574	NEIC	Closed	Cumberland Plateau
CPOT	35.6038	-85.5735	570	TVA	Open	Cumberland Plateau
CP-SO	35.5947	-85.5706	574	LRSM	Closed	Cumberland Plateau Observatory
CRTN	36.1998	-83.8407	488	TVA	Open	Comb Ridge
CSPT	35.761	-83.824	335		Open	Cold Springs
CS-TN	35.8153	-85.1594	579	LRSM	Closed	Crossville
DALG	34.6088	-85.0137	457	ATL	Closed	Dalton
DCT	35.0542	-84.4194	508		Open	Ducktown
ETG	33.2912	-83.3507	137	ATL	Open	Eatonton
ETT	35.326	-84.455	588	CERI	Open	Etowah
FDKY	36.79	-85.7942	306	TVA	Open	Freedom
FGTN	36.434	-83.195	500	CERI	Open	FlatGap
GBG	33.4985	-83.2112	173	ATL	Open	Greensboro
GBTN	35.666	-84.211	326	CERI	Open	Greenback
GLT	36.3617	-86.4983	159	CERI	Open	Gallatin
GMG	34.8627	-84.6703	1097	CERI	Open	Grassy Mountain
GOGA	33.4112	-83.4666	150	NEIC	Open	Godfrey
HGA	34.2602	-85.8464	384	ATL	Open	Collinsville
HPKT	35.926	-83.879	305	TVA	Closed	Knoxville
HVA	34.0264	-86.7692	195	ATL	Open	Hanceville
LA-GA	34.8572	-85.45	610	LRSM	Closed	Lafayette
LCAL	34.5225	-85.6302	544	TVA	Closed	Lambert Chapel
LE-TN	35.6347	-86.7672	213	LRSM	Closed	Lewisburg
LF-TN	36.4697	-83.8286	366	LRSM	Closed	LaFollette
LKGA	34.6233	-85.4722	655	TVA	Open	LookoutMountain
LMTN	35.8868	-83.4098	610	TVA	Closed	LittleMountain
LRAL	33.0348	-86.9978	130		Open	Lakeview Retreat
LRKT	35.634	-83.924	780		Open	Look Rock
MM-TN	35.5644	-85.5889	381	LRSM	Closed	McMinnville
MSAL	34.8467	-86.6735	260	TVA	Open	Monte Sano
MVLT	35.734	-83.942	0		Open	Maryville
MX-TN	35.5503	-86.27	305	LRSM	Closed	Manchester
MYNC	35.0739	-84.1279	550	NEIC	Open	Murphy
OCA	34.6138	-86.4352	250	ATL	Open	Owens Crossroads
ONTN	36.4815	-84.4433	635	TVA	Open	Oneida
ORT	35.9095	-84.3048	370		Open	Oak Ridge
PDTN	35.2733	-85.8495	335	TVA	Open	Piedmont
RCG	34.975	-85.348	468	CERI	Open	RockCity
RCT	35.3453	-84.6614	265		Open	Riceville
REG	33.4421	-83.3371	178	ATL	Open	RockEagle
RHT	35.0781	-84.8825	299		Open	Red Hill
RMG	34.3679	-85.2816	244	ATL	Open	Rome
RSCP	35.6	-85.5689	581	NEIC	Closed	Cumberland Plateau
SMTN	36.382	-83.182	768	CERI	Open	Short Mountain
SSKY	36.7955	-85.7925	300	TVA	Closed	SummerShade
SWET	35.2163	-85.932	581	CERI	Open	Sewanee
SWTN	35.3002	-86.0763	305	TVA	Closed	Sewanee
TDA	33.5417	-86.0247	181	ATL	Open	Talladega
TKL	35.6581	-83.7742	350	CERI	Open	TuckaleecheeCaverns
TLT	35.3011	-84.2833	512		Open	TellicoPlains
TQTN	35.516	-84.7258	260	TVA	Open	Tranquillity
TSTN	35.6766	-83.704	341		Open	Townsend
TVGG	34.3772	-85.3023	323	ATL	Closed	Rocky MountainNet
UGRT	35.6109	-84.117	302		Open	Union Grove
WDG	33.344	-83.1752	177	ATL	Open	Wallace Dam
WMTN	35.248	-84.9732	378	TVA	Open	WhiteOak Mountain

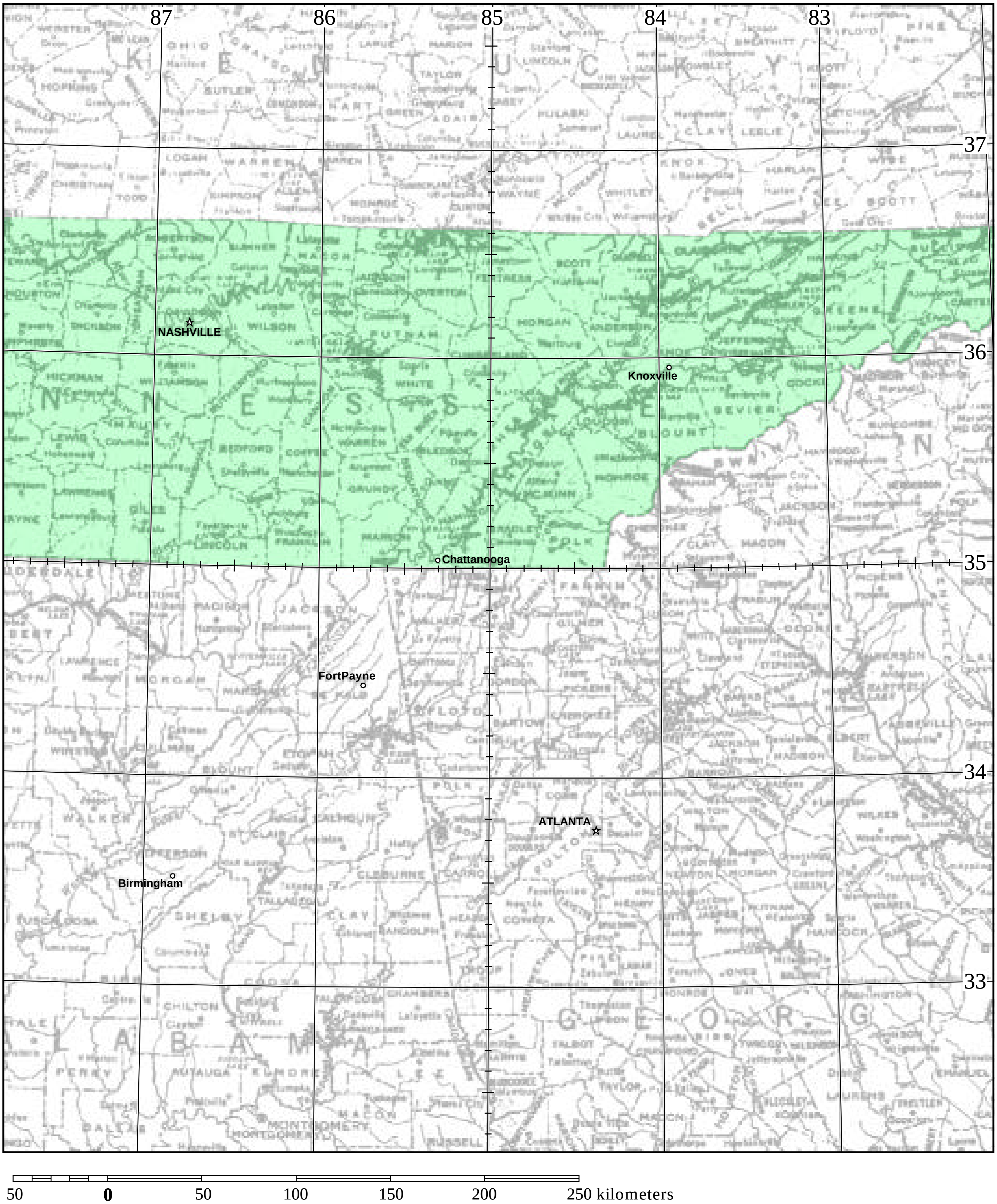


Figure 8. Map of southeastern Tennessee and adjacent states. (From USGS 1:1,250,000 scale maps.) Grid is latitude (33°N to 37°N and longitude (83°W to 87°W). This map should include epicenters determined from seismograms in Figure 4. Epicenters could also be plotted on a highway map of the southeastern United States that includes latitude and longitude.