STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

INFORMATION CIRCULAR 26

EARTHQUAKES

and

EARTHQUAKE HISTORY of ARKANSAS

By

Kern C. Jackson

Little Rock, Arkansas
1979
REPRINTED 1992

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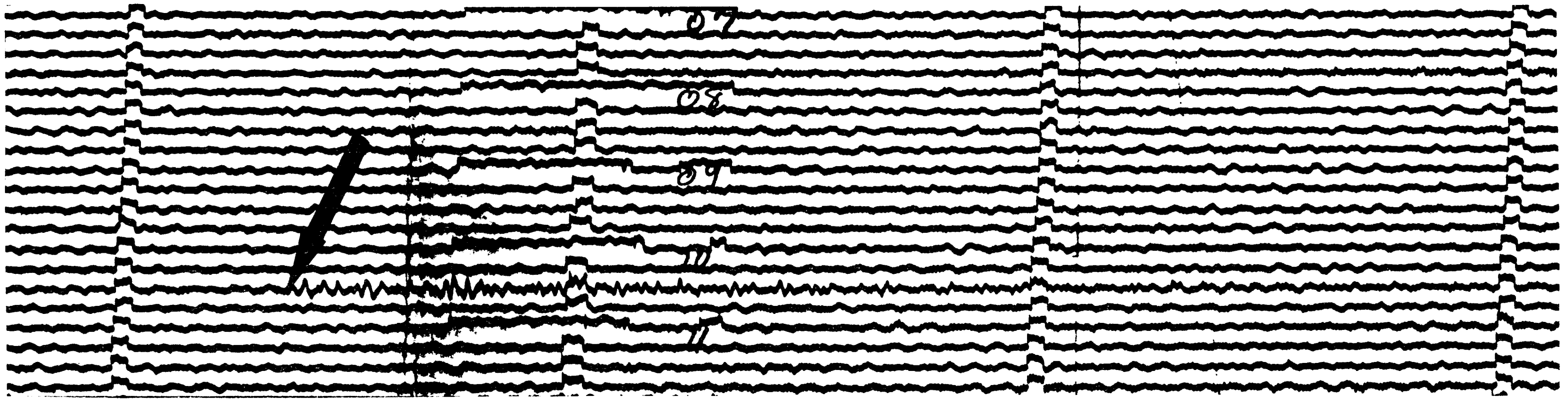
AN EARTHQUAKE – WHAT IS IT?

An earthquake is a sudden movement of the ground that is perceptible to our quite insensitive feet. Almost continual vibrations are passing through the ground, but we, fortunately neither feel them nor recognize their presence. Sensitive instruments can pick up the vibrations caused by the wind blowing through trees or shaking telephone poles with no difficulty. Similarly such instruments can pick up the vibrations caused by waterfalls, waves crashing on the beach, and many curious effects of the weather (Figure 1). The expansion and contraction of the ground as frost forms between the soil particles, and, curiously, the passage of weather frontal systems cause recognizable vibrations. Of course man and his machinery and traffic cause similar, but recognizably different ground vibrations (Figure 2). But these are not earthquakes, merely the background noise that is essentially continuous through which the seismologist must search to find the true earthquakes.

The true earthquake is a single and essentially instantaneous event which results from the continual changes which take place with the Earth. There are many causes for these internal changes. Our present state of knowledge indicates that the surface of the Earth is made up of a series of large plates that are moving relative to each other (Figure 3). Some plates are moving apart, some colliding, and some sliding past each other; all motions are of rates estimated to be a few centimeters per year. The great majority of earthquakes on a worldwide basis are related to motions along boundaries of these plates. The driving force causing the plate motions appears to be temperature differences deep within the Earth. Arkansas is near the middle of one of the great plates so is not involved in this jostling at plate boundaries as California is.

Change is also brought on by the redistribution of weight on the surface of the Earth. Erosion of mountains and building of river deltas involve the slow change of surface mass distribution, removing mass from one area and adding it to another. Similarly the building of great volcanoes like Hawaii or the

August 29, 1975



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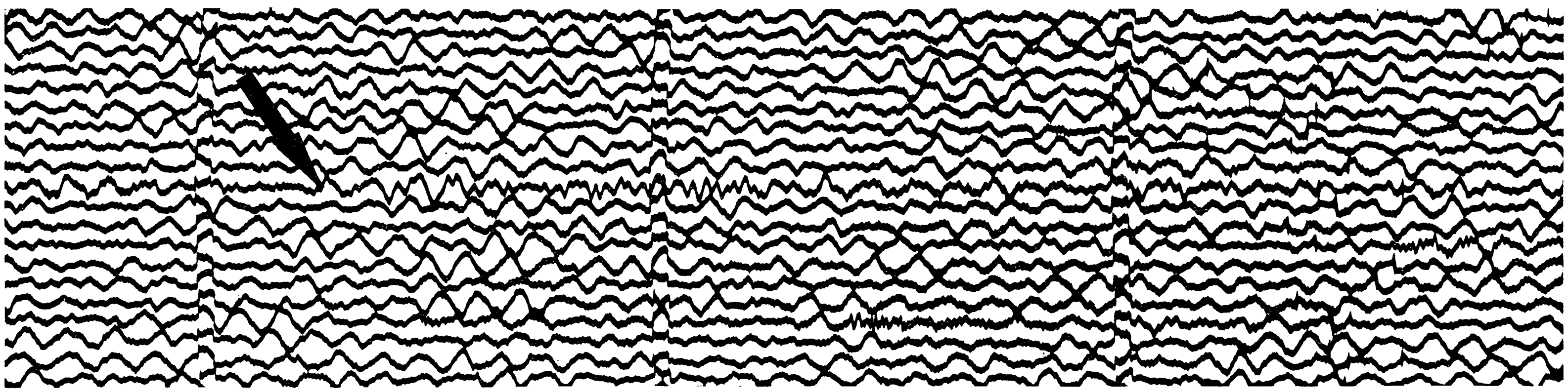

Figure 1 - Weather induced ground vibrations called microseisms. The upper figure is a normal day with a readily recognizable small earthquake. The lower figure was recorded on a microseismically active day with a small earthquake difficult to recognize.

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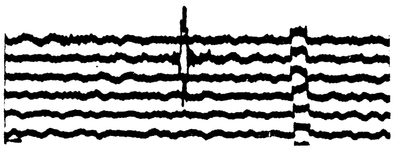
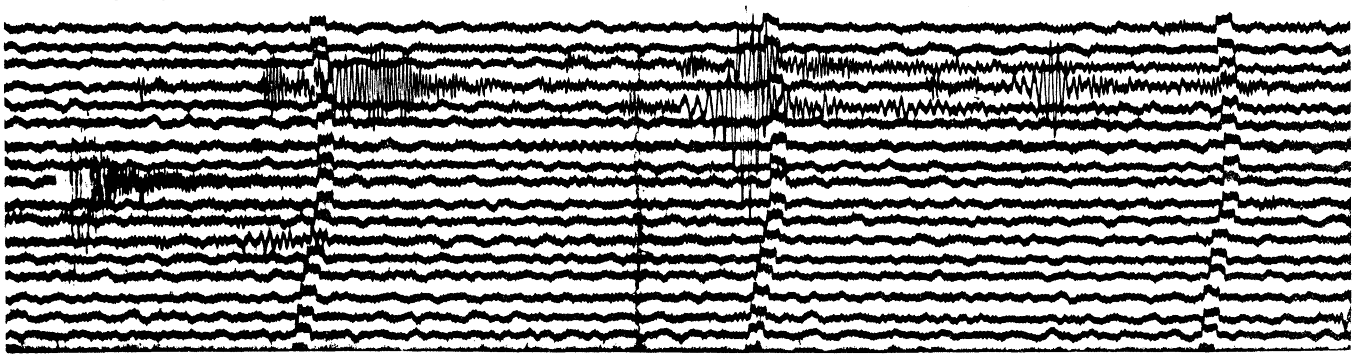


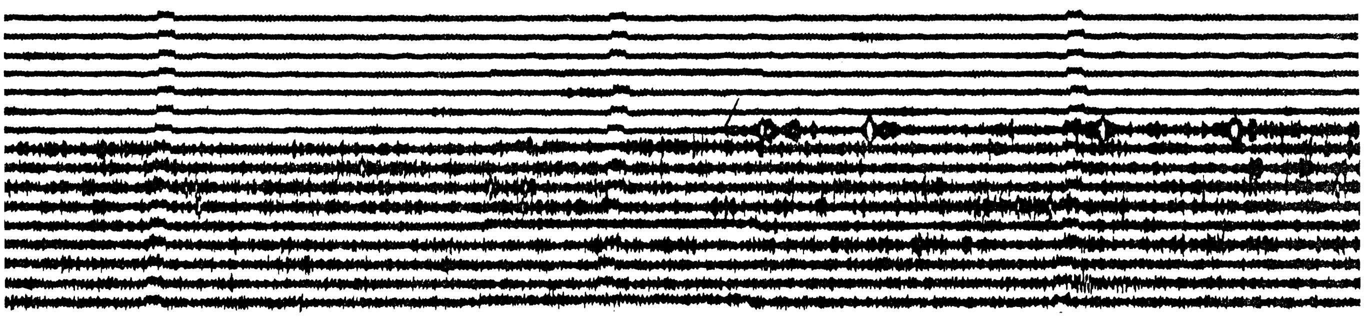
A — Quarry blast 2 km from seismograph station.

February 22, 1975



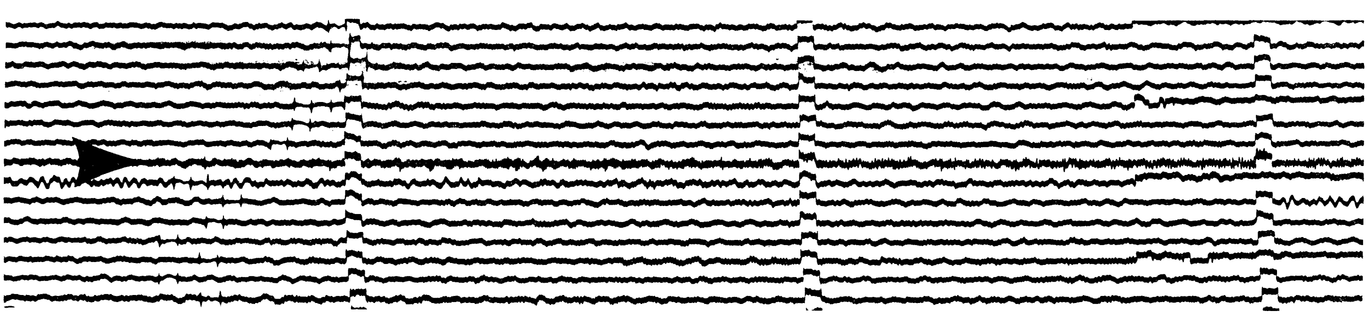
B —Six quarry blasts from at least three different quarries.

May 13, 1975



C — Rock crusher at quarry 2 km from station operating in lower portion of record example.

June 14, 1975



D — The 3:30 AM freight train 3 to 4 miles from instrument station causes the fuzzy line indicated. The train can be recognized for about seven minutes on the record.

Figure 2 - Man-made noise.

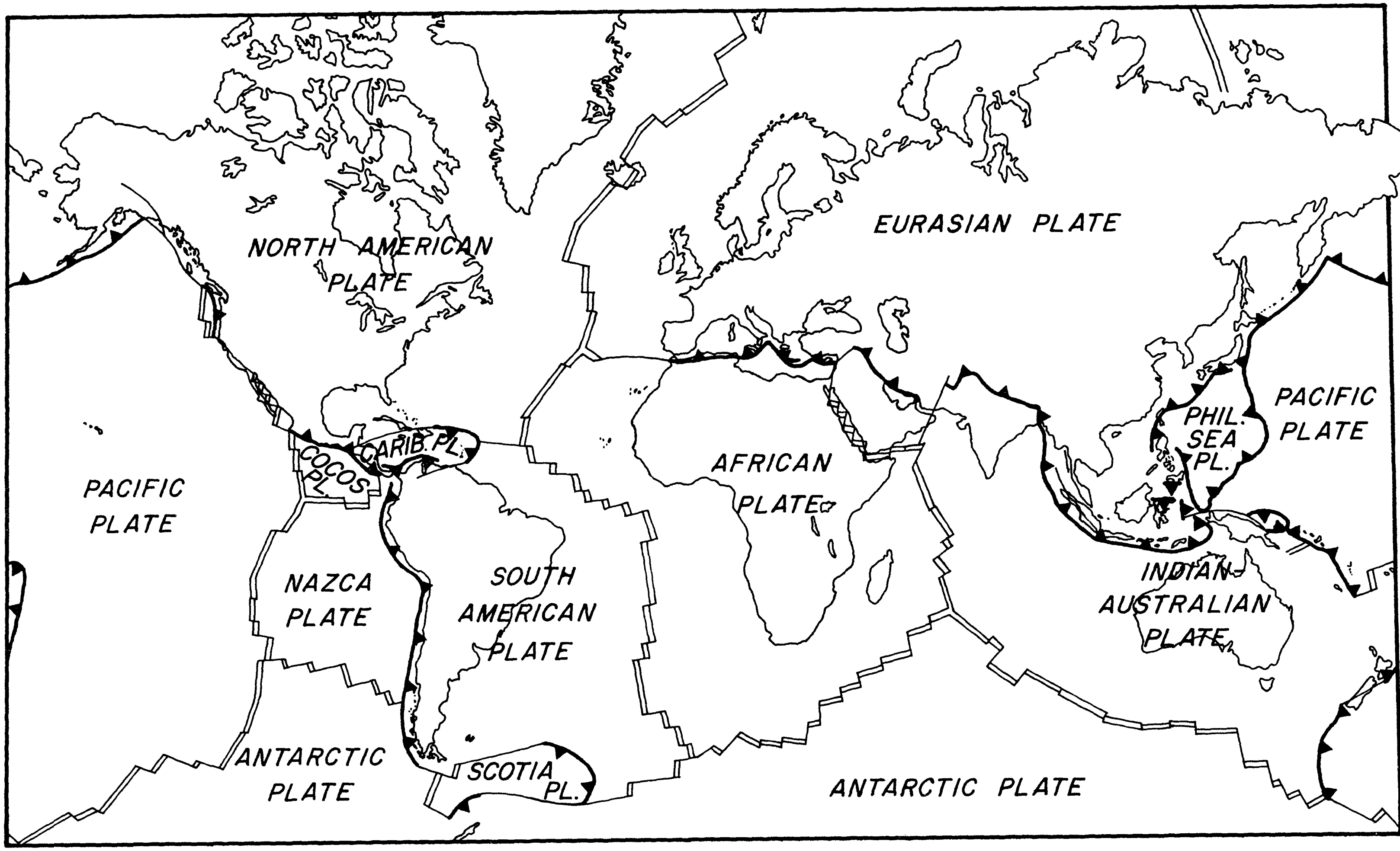


Figure 3 - Plates of the Earth's surface. The plate boundaries are defined by belts of high earthquake activity.

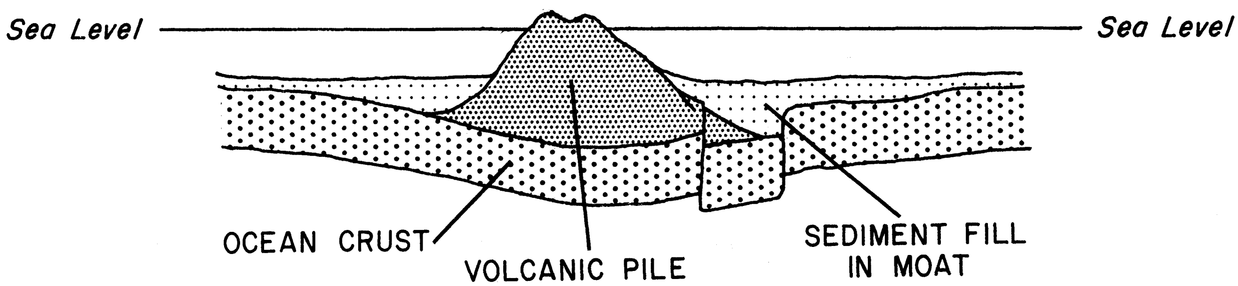


Figure 4 - Bending of the crust due to load. A construction across Hawaii based on geophysical data. The mass of the volcanic pile has bowed down the ocean floor a distance of 3 km and the load has been spread out 300 km laterally. (modified from Woolard, 1954)

Cascades involves loading the crust (Figure 4). Man does the same thing on a smaller scale but much more rapidly when he builds dams and impounds deep lakes. The removal of surface weight by erosion results in the slow uplift of the eroded area. Loading of the surface causes bending and subsidence of the crust. In the process of uplift and subsidence earthquakes may occur as the rocks fracture rather than bend. As we build large structures we hope that the underlying rocks will bend, slowly distributing the weight over a broad area, but sometimes it doesn't work and a series of small earthquakes will occur. This has happened in the area around Lake Meade since Boulder Dam was completed.

Readjustment on ancient fractures, often buried under thousands of feet of younger rocks, is the apparent source of many earthquakes. A fracture which has been encountered by deep drilling for oil and gas extends across Oklahoma, Kansas and Nebraska. The fracture developed some 300 million years ago and is completely buried by younger rocks. Yet this fracture is the source today of minor earthquakes which will be described in this Circular as belonging to the "Nemaha Ridge" belt. Similarly the numerous small earthquakes which extend along the Mississippi River from Memphis, Tennessee to Cairo, Illinois appear to be related to an ancient deep fracture, one which has yet to be encountered by the drill. Apparently the great plate to which North America belongs is not rigid, but is itself broken by fractures along which there is minor movement. Whether this movement is "jostling" or the result of loading or unloading is not clear.

We can visualize the process which results in earthquakes in the following manner: Over time, stress accumulates in the rocks of a region. Probably the most important source for this accumulated stress is from the heat budget of the Earth's interior. At any rate, tremendous energy accumulates in the rocks in a region much as energy is stored in a tree branch when it is bent. Ultimately the stored energy becomes too great for the rocks to retain any more and the rocks are broken by a fracture just as a branch will break when it is bent too far. This fracture becomes a fault along which further movement can take place. The accumulation of stress in the rocks may not be relieved by the simple act of breaking, but the stress may continue to accumulate over long periods of time. In earthquake areas

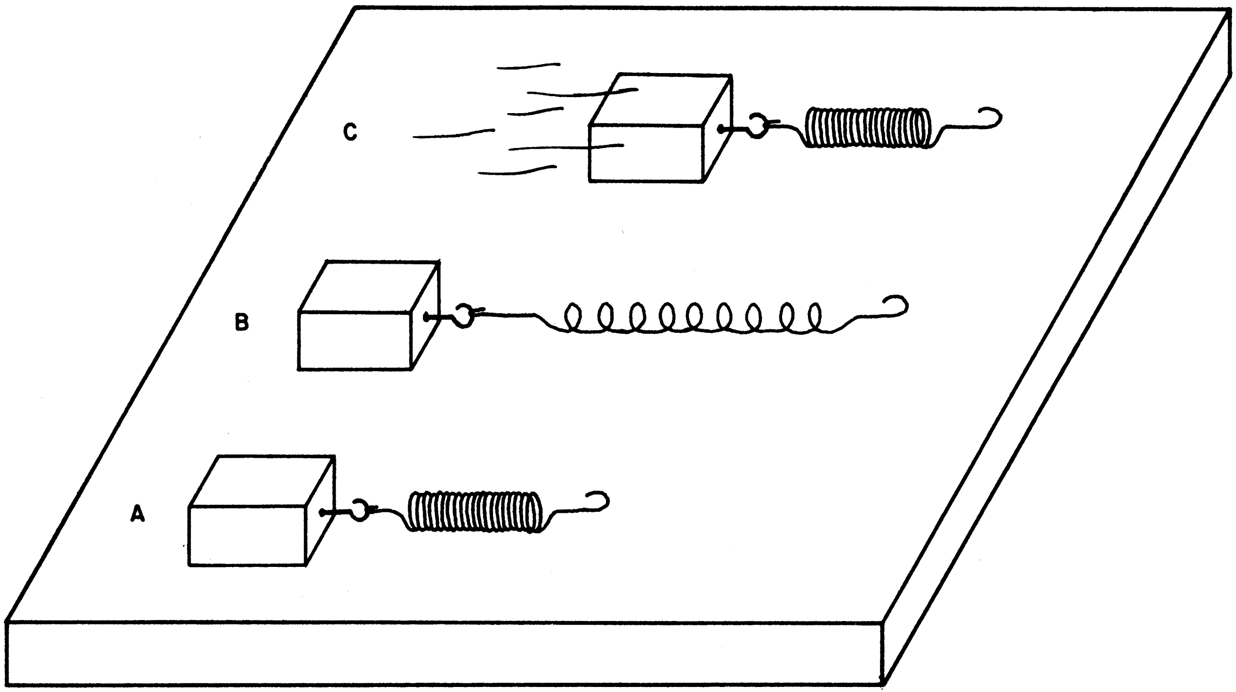


Figure 5 - The stick-slip process is analogous to pulling a brick across a table with a spring (A). Friction holds the brick in place as the spring is stretched (B). When the brick moves it jumps relaxing the spring (C). The spring must be stretched again before the brick moves again.

movement on the fracture or fault is a stick-slip process. Friction on the fracture is great so that continual movement cannot take place. Instead as stress accumulates the rocks again begin to bend like our bent branch. Ultimately, however, the stress will exceed the friction on the fracture and a sudden movement will take place. This sudden movement results in the earthquake (Figure 5).

When the movement takes place there is a sudden release of a tremendous burst of energy almost as in an explosion. The rocks in the area of movement vibrate in a series of very complex movements. This vibration creates waves which radiate outward from the source in all directions. Three fundamentally different types of waves are recognizable. The first are compression - dilation waves similar to sound waves. Such waves can be produced by hanging a "Slinky" spring toy by strings and giving a quick jerk to one end. The waves will then pass along the spring to the other end. These waves travel through rocks at various speeds depending on the character of the rock. At a distant station these push-pull waves arrive first in the series of earthquake waves and are therefore called the "Primary" waves (Figure 6A). The second type of waves are shake waves called shear waves and are similar to waves on water. Again they travel through rocks at various speeds depending on the character of the rocks; however, their velocity is only about six tenths of the velocity of primary waves in any particular type of rock. Therefore at a distant station the shear waves arrive after the

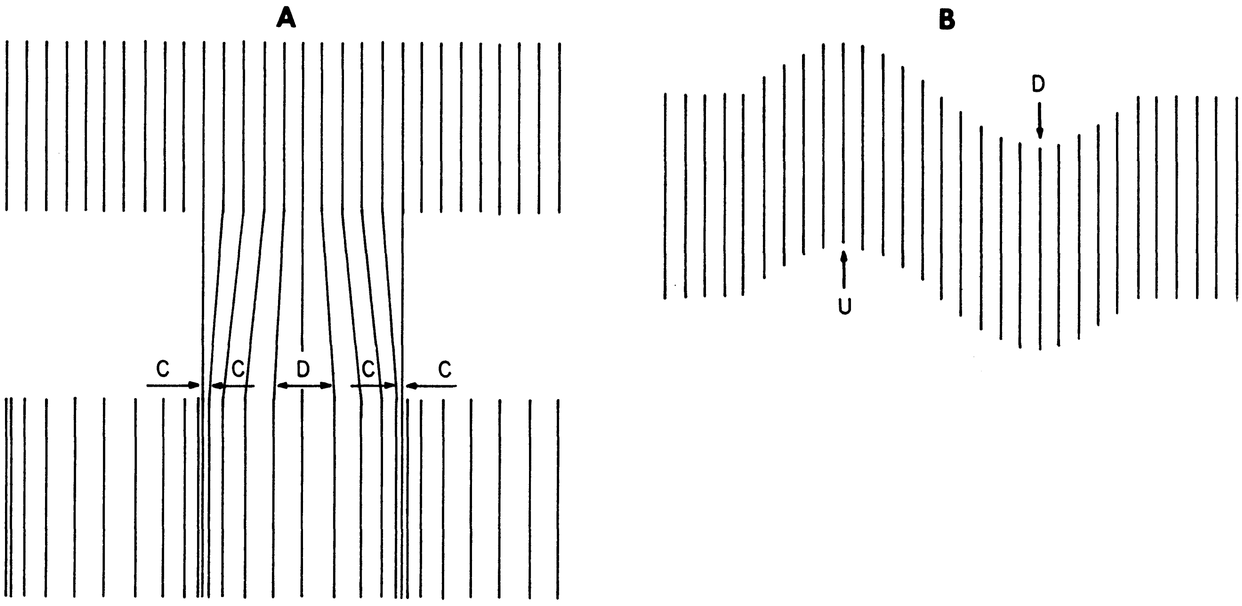


Figure 6 - (A) The nature of P wave motion shown by the schematic displacement of equally spaced lines perpendicular to the direction of wave travel. The lines are connected through to their original positions for one wavelength. C— compressional zone; D— dilational zone. (B) The nature of S wave motion shown by the schematic displacement of equally spaced lines perpendicular to the direction of wave travel. A single wave length of S motion is shown. (Taken from Jackson, 1970)

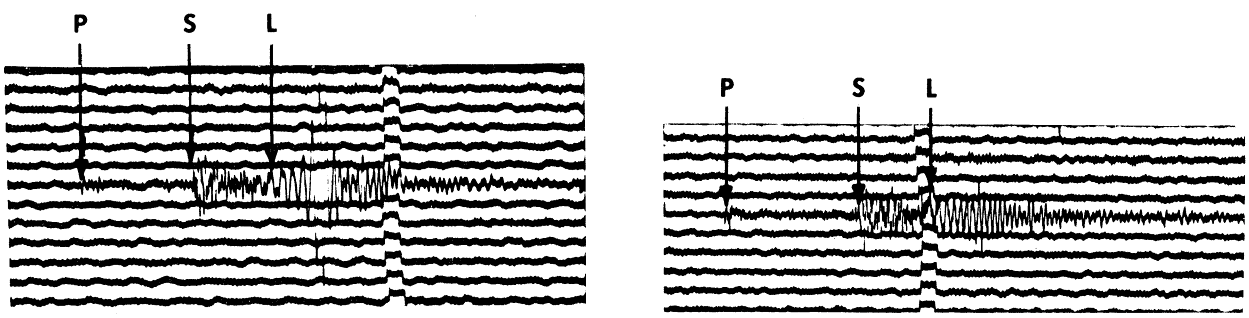


Figure 7 - Two quarry blasts with marked P, S, and L waves. P has the highest velocity therefore arriving first, the "Primary" phase. S has a lower velocity arriving later and therefore the "Secondary" phase. L waves are the largest and have a longer period therefore "Long period" waves. S—P is the time lapse between arrival of the P and S waves in seconds and is a measure of the distance the waves have traveled.

primary waves and are called the "Secondary" waves (Figure 6B). Both the primary (P) and the secondary (S) waves travel through the solid body of the Earth. The third group of waves involve both shake and push-pull motions in a complex pattern. However they travel only over the surface of the Earth and hence are called "surface" waves in contrast to the others which are called "body" waves. Surface waves are designated L, meaning long period waves (Figure 7).

The waves described above are "the earthquake". Of them the surface waves are the most damaging for several reasons. They have the greatest amplitude of motion and the most complex motions, and therefore result in the greatest distortion of structures. The actual ground displacement along the fault when the earthquake originates will, of course, tear structures straddling the fracture in two, but this accounts for only a minor portion of the total damage in the area. Secondary effects of earthquakes are far more important in total damage. These effects include land sliding, fissuring due to ground subsidence, and mud flows of water saturated weak sediments. Gas and electric lines ruptured by the earthquake start raging fires which are rendered uncontrollable by ruptured water mains.

EVALUATING EARTHQUAKE DAMAGE – THE INTENSITY SCALES

The evaluation of the effects of earthquakes was first attempted in 1858 by Robert Mallet in the study of a destructive earthquake near Naples, Italy. His purpose was to understand more fully the mechanics of the earthquake which he thought of as an explosive process connected to volcanos. This type of study has continued and currently is of great importance to engineers involved in construction in earthquake-prone areas. Mallet only recognized four levels of destructive effects, but subsequently two much more elaborate scales were introduced. These are the "Intensity" scales of Rossi and Forel introduced in 1884 and the Mercalli scale first introduced in 1902. At the present time most damage effects are described in the Mercalli scale as modified in 1931 to accommodate modern construction methods and modern machinery such as automobiles. These scales are based on the evaluation by a trained observer of the effects reported by people who felt the earthquake. In the old Rossi-Forel scale the effects are evaluated on a scale of I to X and on the Modified Mercalli scale they are evaluated on a scale of I to XII. Roman numerals are used to indicate that these are empirical scales and indicate relative rather than measured values. The observed effects range from Intensity I which is an earthquake felt only by people in very favorable locations and at rest, to Intensity XII - total destruction. Effects observed include such things as rattling of dishes, swinging of doors, cracked plaster, rustling of trees, ringing of bells, etc. and include behavior of people ranging from simply noticing the effect, to alarm, to panic.

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(As taken from the Earthquake Information Bulletin, Vol. 9, No. 4, July-August, 1977).

I. Not felt—or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway; doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive or nervous persons. Also, as in grade I, but often more noticeably; sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may swing, very slowly; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light or lightly loaded trucks or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Slightly disturbed liquids in open vessels. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most; outdoors direction estimated. Awakened many or most. Frightened few, slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows, in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls or swung them out of place. Opened or closed shutters, abruptly. Pendulum clocks stopped, started, or ran fast or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang, church, chapel, school, and so forth. Damage slight in poorly built buildings. Fall of plaster, in small amounts. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all, general alarm, all ran outdoors. Some or many found it difficult to stand. Noticed by persons driving motor cars. Trees, bushes shaken moderately to strongly. Waves on ponds, lakes, running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, and so forth. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, and so forth. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amounts, also some stucco. Broke numerous windows, furniture, to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line, sometimes damaging roofs. Fall of cornices from towers, high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general, alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly, branches, trunks broken off, especially palm trees. Ejected sand, mud, in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse; racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs, underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, and so forth. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures, bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry, frame structures, also their foundations. Bent railroad rails slightly. Tore apart, crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many, widespread, varying with ground material. Broad fissures, earth slumps, land slips in soft, wet ground. Ejected water in large amount charged with sand and mud. Caused sea waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments, often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, thrust them endwise. Put pipe lines buried in earth completely out of service.

XII. Damage total, practically all works of construction damaged greatly or destroyed. Disturbances in ground great, varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous, extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal, vertical offset displacements. Water channels, surface, underground disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, and so forth. Waves seen on ground surfaces (actually seen, probably in some cases). Distorted lines of sight and level. Threw objects upward into the air.

The intensity of an earthquake varies from a maximum in the immediate area of the shock to zero at some distance, zero meaning "not felt". In general intensity decreases radially from the center, but the variation is normally not uniform. At a distance the felt effects depend primarily on the thickness and character of the soil resting on bedrock. The great New Madrid earthquakes of 1811 and 1812 in southeastern Missouri were felt as far away as Boston, Massachusetts, Charlotte,

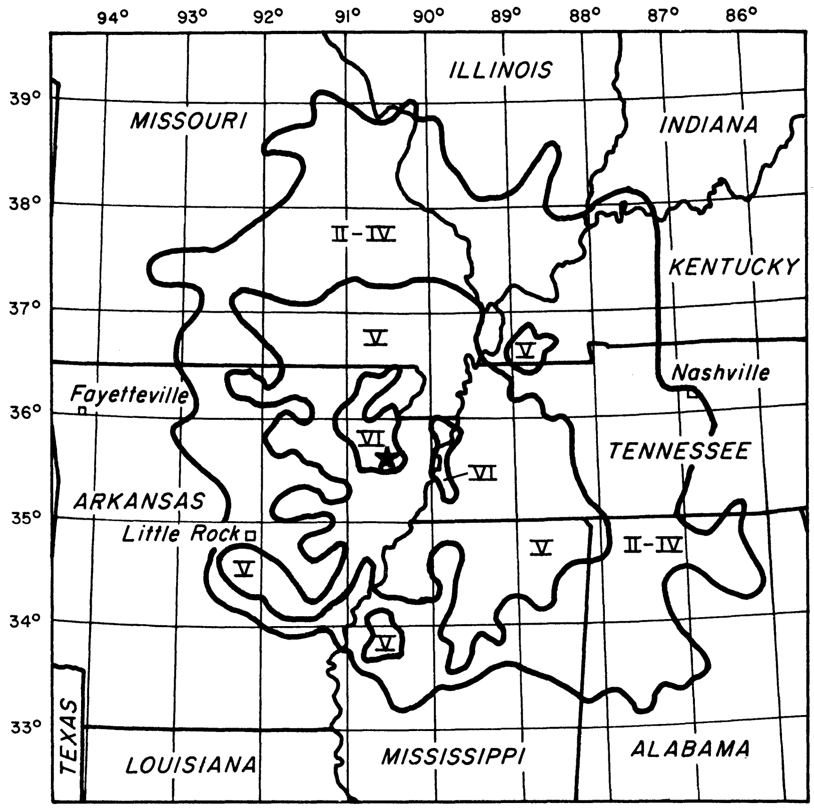


Figure 8 - Intensity zoning of area affected by March 25, 1976 Earthquake. (Modified from USEq, 1976)

North Carolina, and in the headwaters of the Missouri River, and caused damage in Cincinnati but apparently did not awaken people in central Kentucky. The difference between the felt effects in central Kentucky and elsewhere is that the distant places are all located on river flood plains or the coastal plains whereas in the central Kentucky hills there is a very thin blanket of soil on top of solid rock. In all cases river bottom land, coastal swampy lands, and especially man made lands are susceptible to much more extensive damage than area with a thin natural soil on top of rock.

The evaluation of the intensity of an earthquake at a given town is difficult at best. In interviewing individuals the state of mind, ranging from unbelief to abject fear, makes each response different. Evaluation from published newspaper reports is also difficult because the response varies from depreciation of the events for economic reasons to sensationalization. What is the greatest local earthquake in a decade in one paper may be as an insignificant event in another paper, and both may be completely correct. Thus evaluation of intensity is best left to trained observers. However, once intensities have been assigned to all available localities in the felt region of an earthquake, a map can be drawn with lines separating regions of one intensity value from the next. Such lines are called "isoseismal lines" (Figure 8). The area of maximum felt intensity is called the Meizoseismal area and the volume within the earth at which the first faulting motion took place is assumed to be under this area. The major modern value of these maps is that with long time accumulation of data we can generally predict what is the most damaging earthquake effect that can be reasonably expected in any given area. This is very important in engineering problems. For instance, before any nuclear power generating plant can be constructed such an evaluation is required by the Atomic Energy Commission, and then the reactor chamber must be designed to withstand earthquake shocks several times that of the maximum ever felt in the area (Figure 9).

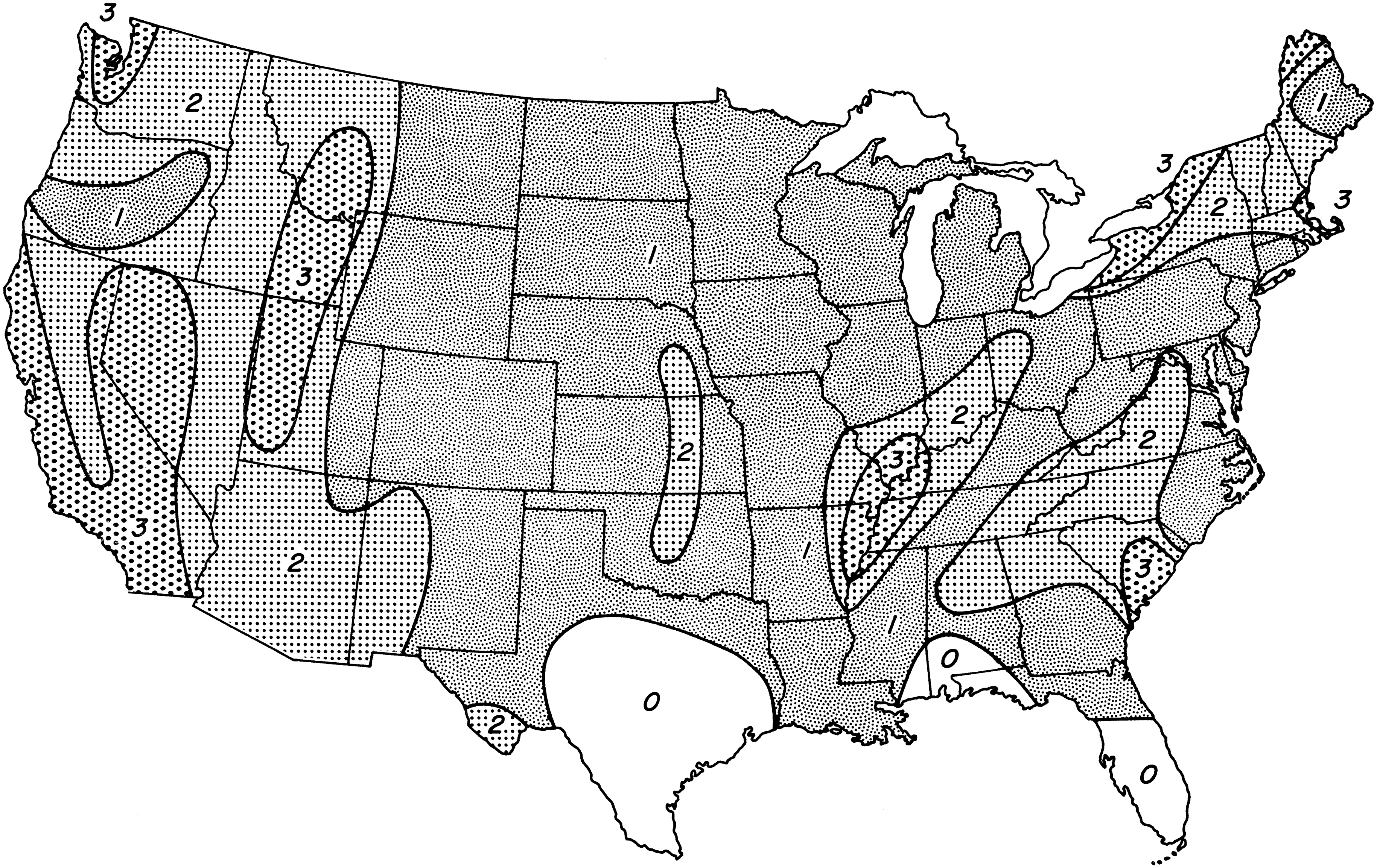


Figure 9 - Seismic risk map for conterminous United States. Zone 0 — no damage. Zone 1 — minor damage; corresponds to intensities V and VI of the M. M.* scale. Zone 2 — moderate damage; corresponds to intensity VII of the M. M.* scale. Zone 3 — major damage; corresponds to intensity VIII and higher of the M. M.* scale. (* — M. M. refers to the Modified Mercalli Intensity Scale.)

In 1931 Gutenberg and Richter were preparing a catalog of all instrumentally recorded earthquakes in California and Nevada. They decided that simply listing them all without any indication as to their relative size was undesirable so they set out to find a method of relative evaluation. Fortunately, the network of seismic stations with which they were working all had identical instruments calibrated to the same magnification. This meant that a given displacement of the ground by an earthquake would result in the same amount of displacement of the instrument record trace on any of the instruments in their network. The measured displacement of the record trace for the thousands of earthquakes they were studying varied from barely discernible (0.1 mm) to well over 1,000 mm. Because of this wide range of instrument trace amplitudes they decided to plot the logarithm of the trace amplitude against the distance of the instruments from the source of the seismic waves. The results were amazingly consistent, with the log amplitude decreasing systematically with distance for all earthquakes large and small. This led to the concept of a magnitude scale, commonly called the Richter scale. It is a logarithmic scale to the base 10; that is, each numerical value of the scale involves ground motion in an earthquake which when recorded instrumentally and magnified would result in a record trace amplitude ten times that of the next lower number (Figure 10).

Gutenberg and Richter initially arbitrarily defined a 0 magnitude earthquake as one which would cause a trace displacement of 0.001 mm on their instruments at a distance of 100 km. It does not mean "no earthquake" because at a distance of 5 to 10 km it would probably be recorded and identifiable. In fact, even negative magnitude earthquakes (that is quakes smaller than a 0 magnitude) are identified, for instance in association with volcanic eruptions in Hawaii. By the original definition of a 0 magnitude then, a magnitude 1 earthquake would write a trace amplitude of 0.01 at 100 km, a magnitude 2 earthquake would give a trace amplitude of 0.1 mm at 100 km, a magnitude 3 earthquake would give a trace amplitude of 1.0 mm at

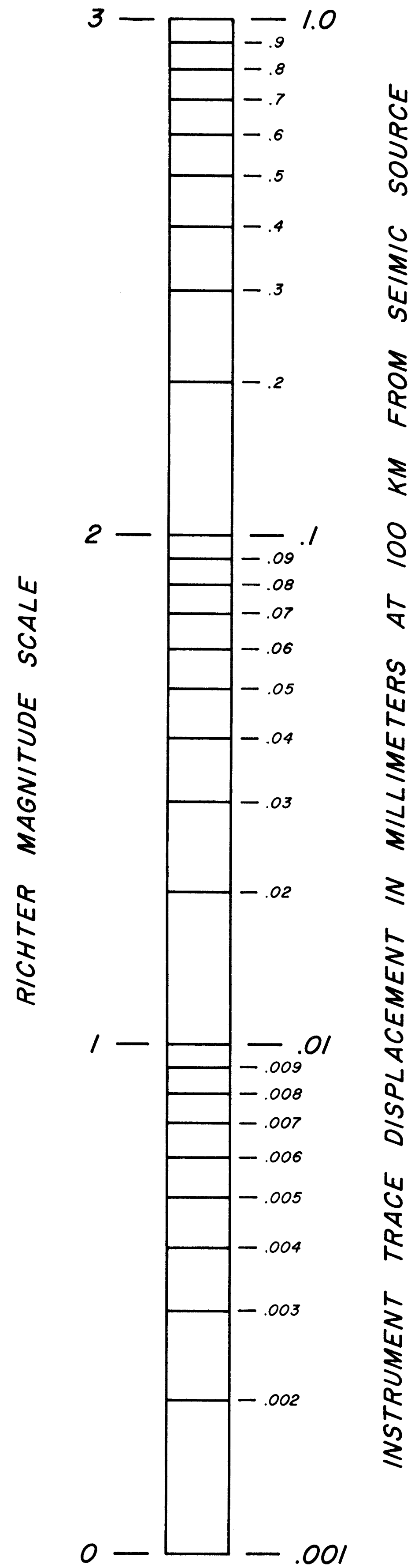


Figure 10 - A logarithmic scale.

100 km, a magnitude 4 earthquake would give a trace amplitude of 10 mm at 100 km, etc. This is a "log to the base 10 scale" and is often misinterpreted by the news media as a "scale of 10."

The entire magnitude scale has been subsequently expanded and refined so that it is applicable to any earthquake anywhere on Earth and is not limited to the California-Nevada area. Furthermore modern instruments are more sensitive and have higher magnification than those of the 1931 network allowing evaluation of smaller, more distant events. Thus an earthquake felt at Oak Ridge, Tennessee on May 14, 1975 was assigned a magnitude of 2.5, but at Fayetteville 840 km distant it wrote a record with a maximum trace amplitude of 1.3 mm. Magnitude can be calculated from the data of any properly calibrated seismometer, but the assignment of magnitude is generally made by a relatively few highly calibrated stations. Subsequent detailed work has indicated that the magnitude of an earthquake is directly related to the total amount of energy released during the seismic event.

Unlike intensity which decreases outward from the meizoseismal area, the magnitude of an earthquake is everywhere the same. Because distance enters into the definition, a Mexican earthquake should give the same magnitude from the records in both Berkeley and Boston. In actual practice this does not quite work out because of the difference of rock conditions under different seismic stations and the difference of the paths of rays from the source to the different stations. From an earthquake in central Mexico the path from the source to Boston would cross the Gulf of Mexico whereas the path to Berkeley is all under continent. Thus different stations will report different magnitudes for the same earthquake, but the variation will not be great.

The two greatest earthquakes recorded since 1906 (when the modern electromagnetic seismometers were invented) were in 1906 off the coast of Equador and in 1933 off the coast of Japan. Each of these quakes has been assigned a magnitude of 8.9. The great Palm Sunday earthquake at Anchorage, Alaska in 1967 was assigned a magnitude of 8.7. The largest quake felt and recorded in Arkansas since 1965 had a magnitude of 5.3. Earthquakes of each magnitude are 8 to 10 times more frequent than earthquakes of the next higher magnitude. That is, quakes with a magnitude of 7.0 to 7.5 are 8 to 10 times more frequent than quakes with a magnitude of 8.0 to 8.5. On the basis of the frequency of quakes we can predict that a quake of magnitude of 10.0 should occur once every 90 years. However, such a quake has never been felt and would be so great that it could not be missed even if it occurred in the remotest part of the Earth. Therefore we conclude that a magnitude 10 quake is impossible, the rocks simply are not strong enough to store the tremendous amount of energy that such a quake would represent. As a result, a magnitude 9 earthquake is considered to the most violent possible.

One of the major values of the magnitude scale has been as a mechanism for estimating the amount of energy released. The formula takes the form

$$\text{Log Energy} \triangleq A + (B \times \text{Magnitude})$$

where A and B are constants ($A \triangleq 7$, $B \triangleq 2$). But the magnitude scale is already a logarithmic scale. Magnitude increases in a sequence of 1 - 10 - 100 - 1,000, therefore energy increases in a sequence of 1 - 100 - 10,000 - 1,000,000! As a result we know that it requires on the order of 10,000 magnitude 5 earthquakes to release the energy of one magnitude 7 earthquake. A magnitude 5 quake is a moderate one that could cause minor damage in a populated area, whereas a magnitude 7 quake is a major one and could cause extensive damage. (The San Fernando quake of February, 1971 that killed 60 people and did a billion dollars damage was of magnitude 6.6). In seismically active areas there is a common tendency for people to assume that three or four minor quakes will have acted as a safety valve relieving the stresses in the rock so that no major quake can occur. This is totally incorrect. It would take hundreds or thousands of minor quakes to relieve the strain in the rocks that would be involved in one major quake. The little pops that are taking place continuously along the San Andreas fault in California will not prevent another great disaster such as the 1906 San Francisco earthquake. Neither will the little quakes that are common in southeast Missouri and northeast Arkansas prevent another great disturbance such as the New Madrid quakes of 1811-1812. As yet we have no way of predicting when either of these areas will be subjected to a major disturbance.

EARTHQUAKE PREDICTION

The problem of the prediction of earthquakes is an area of great current interest. For a prediction to be meaningful it must say *where* within a few miles, *when* within a few days, and *how big* within a small limit on the magnitude scale. Anything less than this cannot be considered "prediction" and would be essentially meaningless. All three requirements must be met if predictions can be acted onto save life or property. Even assuming a high degree of accuracy of prediction there is considerable diversity of opinion as to what action should be taken. Assume that a prediction has been made with 90% certainty that an earthquake of magnitude 5½ to 6½ will occur in a given populated region within a given week, what should be done? A 5½ magnitude earthquake would cause minor damage, whereas a 6½ magnitude could cause extensive damage and probable loss of life. The economic loss and sociological effects of evacuating the area for a week might cost more, without even considering the inevitable looting that would take place. Suppose the area were evacuated and the week predicted passed without an earthquake - what then? Do we assume the prediction was wrong, or wait another few days, attempting to take care of a million displaced persons and safeguarding the abandoned property? Seismologists keep pressing toward a successful method of predicting earthquakes but the government and business leaders are the ones who must plan on what to do with those predictions.

Earthquake prediction involves the recognition, evaluation, and subsequent monitoring of a number of small and subtle changes which appear to take place in the Earth prior to an earthquake. Unlike other natural disasters, such as hurricanes and floods, these precursor events are not visible and cannot be followed from one area to another. Thus for any system to work will require a great deal of instrumentation in each earthquake prone area and a large body of technical personnel. To date a few small earthquakes have been successfully predicted in the United States, but an equal number have been predicted which failed to materialize and many have occurred in regions under study which were not predicted. So far the major success has been in China in 1974 where the people were simply ordered into open areas and shown movies during the predicted time, a one day period.

One of the precursor events which appears to have promise is a small decrease in the velocity of P waves in a region prior to an earthquake. The velocity of S waves at the same time remains about constant, so the ratio of velocity of P to velocity of S is used. These P and S velocities must be obtained from either small earthquakes recorded in the region or from blasting in the region. The limited data show that some time before an earthquake the V_P/V_S value decreases slowly to a minimum, it then builds back up to the normal value, and then the earthquake occurs. The greater the decrease and the longer the time of decrease the larger the earthquake. The decrease in P velocity appears to extend for periods of four months for magnitude 5 earthquakes to three years for magnitude 7 earthquakes. The model offered to explain this phenomenon is called the "dilatency model" and involves microfracturing of rock prior to an earthquake followed by a migration of fluids (predominantly water) into these fractures. The earthquake occurs when the fractured rock becomes saturated with fluid. The model is not completely successful because such a process would necessarily involve other measurable changes, such as uplift of the region, change in electrical resistivity of the earth, magnetic changes, and surface tilting. Where data is available changes in such properties do not always correlate with changes in velocity ratios, but these phenomena and others are being studied as possible indicators of quakes.

A second group of phenomena which are being studied are changes in water wells. Ground water, particularly where it is confined to deeper horizons, is particularly susceptible to stress and warping of the Earth at shallow depth. As a result water level changes in abandoned wells are monitored, looking for abnormal changes in either level or temperature. This technique was one of many used by the Chinese in the prediction of the 1974 quake using thousands of volunteer observers. Related to this is the flow of radioactive radon gas from the Earth to wells. Radon is produced naturally and continuously by the radioactive decay of uranium and is lost to the atmosphere where it decays rapidly. Deformation of the Earth's crust results in abnormal release of the gas which is readily detectable in closed wells.

Many other precursor phenomena have been studied or are being studied. The abnormal behavior of animals days to minutes before an earthquake have moved from the realm of folklore to one of scientific investigation and in an agrarian nation, such as China, is of considerable use. Periodicity of earthquakes is useful where long term records are available. In China these go back 3000 years and in the USSR over 1000 years, whereas in North America we have less than 200 years of records. No one method of prediction is likely to prove successful by itself. A combination of many instrumental and observational phenoma will probably be required with an elaborate network of instrument stations with trained professional and volunteer observers before we can say when, where, and how big an earthquake will be.

HOW ARE EARTHQUAKES RECORDED - THE SEISMOMETER

The first seismometer was developed in 1880 and was purely a mechanically recording instrument using levers to magnify ground motion. The first of the modern electrically recording instruments was developed in 1906. All modern seismometers work in the same fundamental way in that they consist of a mass of material that is suspended in such a way that it stands still while the ground around it moves with the seismic waves (Figure 11). Instruments vary in that they are designed to record only one direction of movement (vertical versus horizontal), and in the method of magnifying and recording the ground motions. In the instruments which were used to record the various vibrations illustrated in this Circular, there is a coil of wire attached to a suspended mass. The coil is surrounded by a permanent magnet attached to the ground. As the magnet moves around the coil an electric current is generated in the coil. This tiny current is amplified and deflects a galvanometer to which is attached a small mirror. A focused light beam is reflected off this mirror to a moving sheet of photographic paper, exposing a moving dot on the paper which, when developed, produces a black line trace on the paper. This trace is not the ground movement. It records current generated in the coil which depends upon the relative velocity of movement of the magnets about the coil. When the relative motion is accelerating the current generated increases and the galvanometer is deflected. As motion decelerates the current wanes and the trace on the paper returns to the base line. Thus one motion in one direction of the ground results in a deflection and return of the trace to the base line. As the ground returns to its original position, the current flows in the opposite direction and the trace is deflected in the opposite direction from the base line. The maximum displacement of the trace line occurs when there is maximum relative velocity between the magnets mounted on the ground and the coil (Figure 12). There are damping devices built into the system to prevent the mass from swinging like a pendulum once the

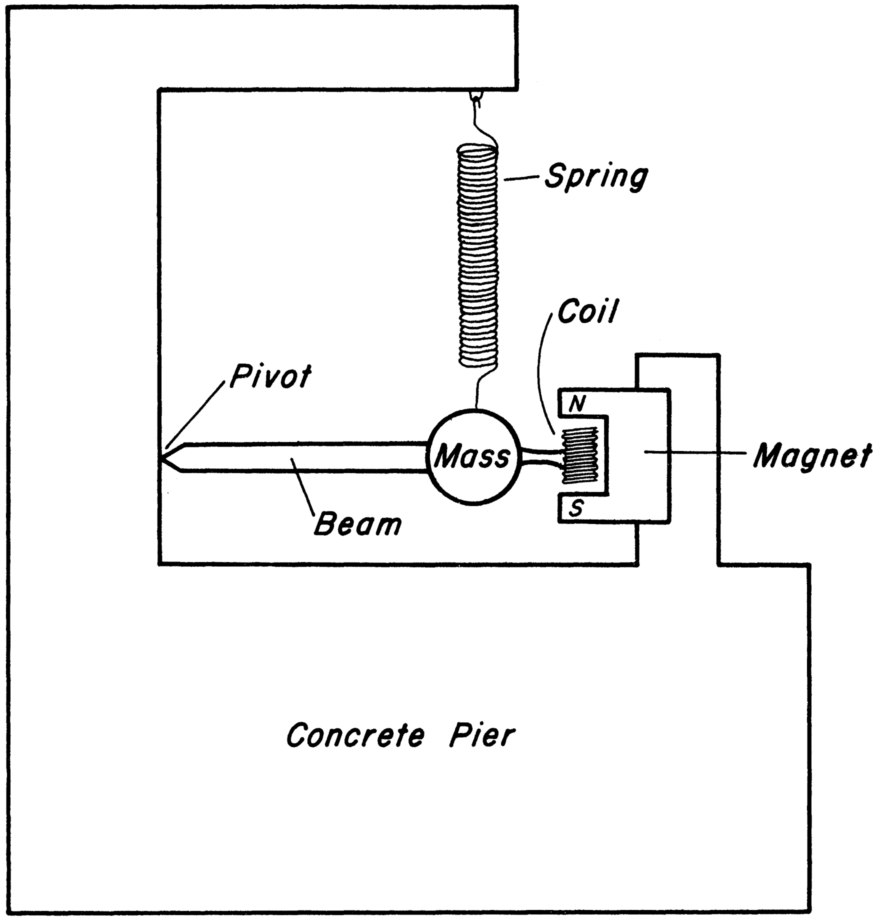


Figure 11 - A simple vertical component electromagnetic seismometer. The mass, supported by the pivot and spring tends to stand still as the pier moves during an earthquake. A current is generated in the coil as the magnet moves around the coil.

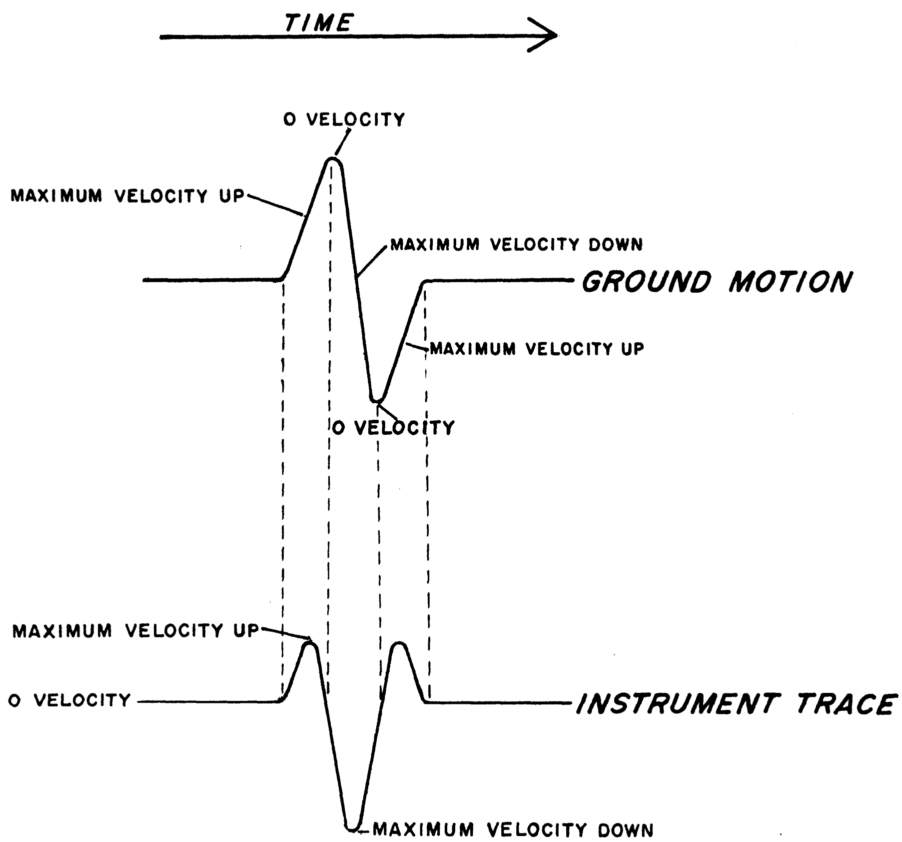


Figure 12 - Ground movement as compared to a seismic record.

motion has started.

Timing of seismic events as they are recorded at the station is imperative. Therefore there is a timing system built into the seismograph. This consists of a temperature-insulated accurate pendulum clock which is checked daily against the US Naval Observatory radio time. The time from this clock is automatically impressed on the record every minute by deflecting the light source for the first two seconds of each minute. Each hour is also marked by a deflection for 35 seconds in the 60th and 1st minutes (Figure 13). By checking the clock accurately, the time of arrival of an earthquake wave can be timed to one-tenth of a second. In looking at the photographs of the records later in this Circular these time markings will be quite evident.

The record is made by wrapping sheets of photographic paper around a cylindrical drum 90 centimeters in circumference. The drum rotates one millimeter per second so that each full rotation of the drum requires 15 minutes. During one revolution the drum is moved horizontally four millimeters so that the trace is actually a spiral line, but when the paper is taken off of the drum it appears as a series of lines, each representing 15 minutes (Figure 14). The time of seismic events can then be read directly, measuring from the beginning of the minute marks one millimeter per second. This time is corrected according to whether the station clock is fast or slow relative to the radio Naval Observatory time. All seismograph stations operate on the same time; this is, the day begins at midnight at the Naval Observatory in Greenwich, England. This is called Greenwich Meridian Time and is six hours ahead of Central Standard Time. Thus the beginning of our seismograph day, 0:00 GMT, is at 6:00 PM CST.

In all modern seismograph stations there are three instruments, and research stations may have as many as a dozen operating at all times. Each unit consists of three instruments, one designed to record the vertical component of the ground motion and two designed to record the horizontal component. The two horizontal instruments are oriented so that one records the north-south component and the other records the east-west component of the horizontal motion. In the multiple set stations each set of three instruments is designed to have its maximum sensitivity in a different frequency of vibration. Further, at the research stations the recording is on magnetic tape rather than photographically so that timing can be more accurate and all of the waves from a single seismic event can be isolated and studied in greater detail.

The vertical component instrument is designed so that if the first motion of the first P wave is a push, a compressional wave, the trace on the record is deflected upward from zero line. In contrast if the first motion is a pull, a dilational wave, the trace is deflected downward from the zero line. Similarly, with the horizontal instruments if the first motion of the first P wave is a push from the west the first motion on the east-west instrument will be an upward deflection of the trace from the zero position. In this manner the approximate direction of an earthquake from the station can be determined (Figure 15). The distance to the earthquake can be estimated by the time difference between the arrival of the first P wave and the arrival of the first S wave. This is possible because the S wave travels through the earth at approximately six-tenths of the velocity of the P wave. They have both traveled the same distance therefore the S–P time is an approximation of the distance. The precise location of the source of the disturbance requires the S–P times of a large number of stations whose positions are accurately known. The more stations the better, although three are sufficient for an approximate determination of the source. The reason for this is that there are subtle variations in the materials of the Earth's mantle which affect velocity. Working backwards, once the source of the waves has been accurately determined, the variations of the arrival times of P and S at various stations can be used to study these subtle variations of Earth materials at depth in broad regions. In Arkansas, for instance, a study of the arrival times from accurately timed quarry blasts from south and southeast of Fayetteville

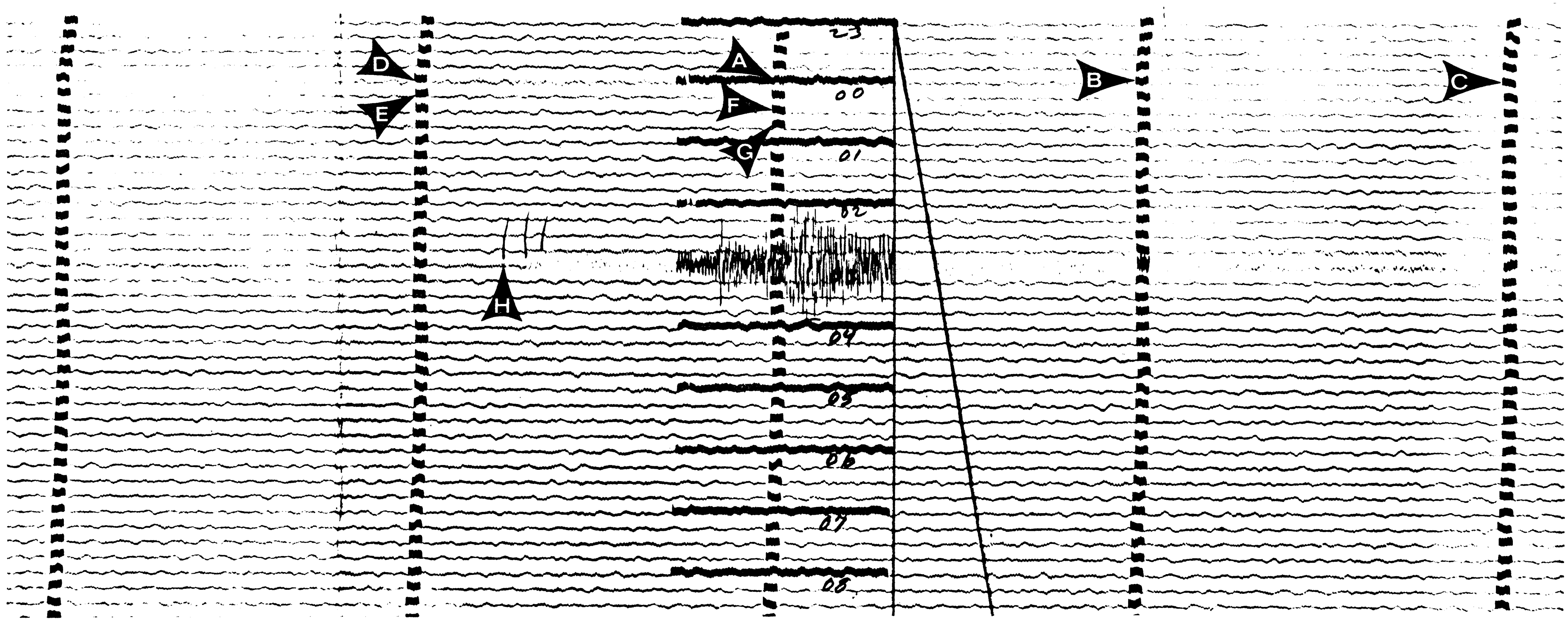


Figure 13 - Time marks on a record. The instrument was slightly out of adjustment resulting in a suppressed record and enhanced time marks. An earthquake from Oklahoma was being recorded at the fifth hour break. Times at points indicated are:

A – midnight Oct. 11, 1975
B – one minute after midnight Oct. 12
C – 00:02:00 Oct. 12
D – 23:59.00 Oct. 11
E – 00:14:00 Oct. 12
F – 00:30:00 Oct. 12
G – 00:45:00 Oct. 12
H – 02:59:14 Oct. 12 beginning of earthquake

FIGURE 14 - The vertical instrument record for the interval 22:20 (4:20 PM, CST) May 25, 1975 through 22:28, May 26, 1975. The very prominent earthquake is from the North Atlantic. The event began at 09.22:26 on this uncorrected record and waves were still recognizable at 12:25. The high amplitude—long period surface waves evident here are typical of large shallow earthquakes. Several other small events are recognizable.

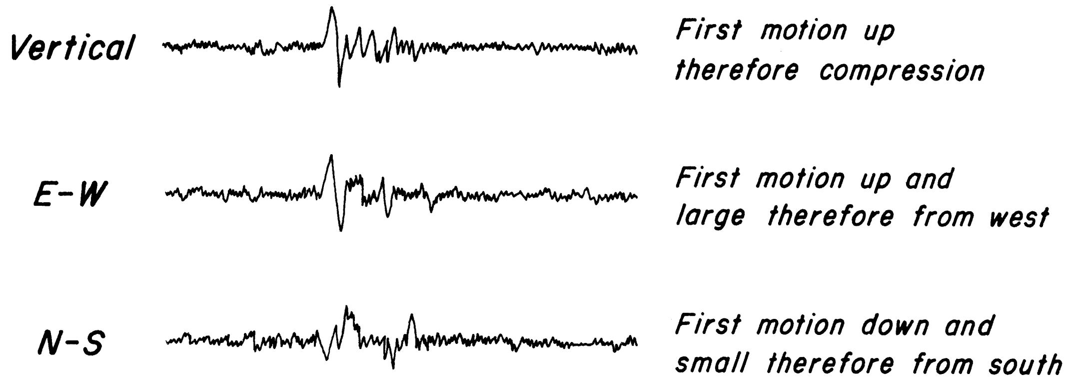


Figure 15 - Determining the direction of an earthquake. First motion in the vertical instrument indicates a compressional wave. First motion on E-W instrument indicates a large component of motion from the west. First motion on the N-S instrument indicates a small component of motion from the south. Therefore the epicenter of the earthquake is west-southwest of the station.

arrived later, therefore traveled more slowly, than waves from quarry blasts north of Fayetteville. South and southeast of Fayetteville there is a thick column of low velocity sandstones and shales at the surface whereas north of Fayetteville the major surface rock type is high velocity limestone. The quarries used for this study were as far away as Little Rock and Fort Smith and Carthage, Missouri. On a broader regional scale, similar variations show up indicating variations of materials up to 100 kilometers in depth. In the United States, stations between the Rocky Mountain front and the Great Valley of California receive first motions of distant earthquakes as much as two seconds later than predicted. This indicates that the materials underlying this area have slightly lower than normal seismic velocities. In contrast some areas east of the Rocky Mountains receives first motions as much as three seconds earlier than predicted indicating that these areas are underlain by materials with higher than normal seismic velocity. These differences may be due to differences of temperature of the rocks under the areas or it may be due to differences in chemical or mineral composition. Some day we may know what the cause is. Nuclear blasts have been particularly valuable in these studies because the location and time of each blast are precisely known.

TRAVEL PATHS OF BODY WAVES THROUGH THE EARTH

Over the decades since the development of the recording electromagnetic seismometer thousands of good records of quakes from all over the earth have accumulated and been studied. The records show that we are not dealing with only simple P, S, and L (surface) waves; but rather that within both P and S there are several pulses of energy that come in at different times. These pulses appear to be compressional or shear waves which have followed different paths through the Earth and have been reflected off of, or refracted through interfaces between contrasting materials within the Earth. These energy pulses are called "phases"; thus we have various P phases and various S phases. The interfaces within the Earth are called "discontinuities" and appear to be boundaries between materials of different physical, chemical, or mineralogical character. Some of the discontinuities appear to be sharp concentric surfaces, but most appear to be gradational changes between materials as concentric shells within the Earth.

The study of earthquake waves and the various phases gives us our best information about the interior of the Earth. The

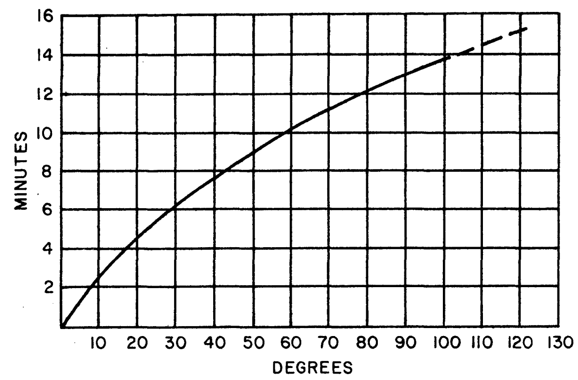


Figure 16 - Time-distance plot of P wave.

approximate velocity of compressional and shear waves can be calculated for each depth in the Earth. These velocities are related directly to the physical properties of the materials. Thus from velocity we can approximate density, rigidity, compressability, and elasticity of the materials of the inner Earth and begin to make reasonable assumptions as to the nature of materials.

The Family of P Phases

When the time required for P waves to travel from the source to a seismograph station is plotted against the distance from the source to the station a characteristic curve is found (Figure 16). This curve shows that the greater the distance from source to station the greater the depth within the Earth that the waves penetrate, and the greater the average velocity of the waves along the path. In other words, the greater the depth within the Earth the higher the velocity. This is what would be expected because of the increase of pressure on the rocks. As a result of this velocity increase, the waves do not travel in a straight line through the Earth, but rather travel along a curved path which is concave towards the surface of the Earth (Figure 17). The waves are refracted in a manner similar to the refraction of light at the surface of a body of water which makes a straight stick appear bent.

In making a time-distance plot, the two coordinates are *travel time* and *arc distance.*

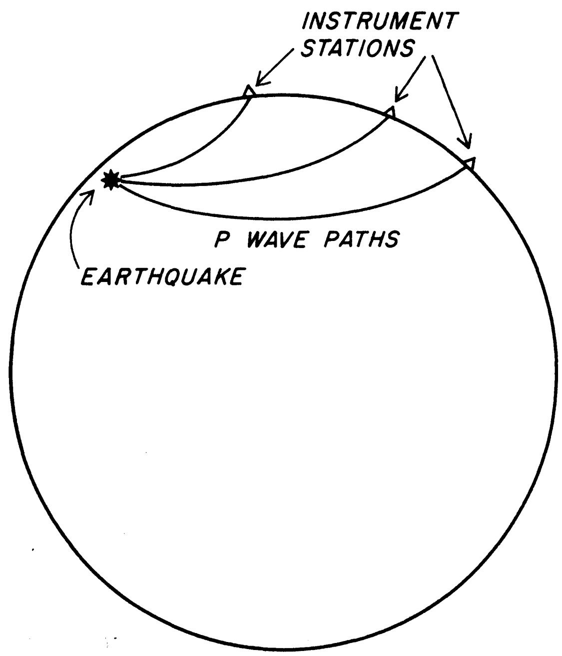


Figure 17 - P wave paths from an earthquake to three seismic stations.

Travel time is the difference between the calculated time of the initial slip causing the earthquake and the time at which the first energy pulse reaches the station. The arc distance is the distance expressed in degrees between the *epicenter* and the station. Epicenter is the point on the surface of the Earth directly above the point of the initial movement in the Earth. Given the latitude and longitude of the epicenter as calculated from several seismic records, and the latitude and longitude of the station, the arc distance can be calculated or measured off of a globe. We can express the arc distance in straight line miles over the surface of the Earth as well as in degrees.

As we plot the time-distance curve for the first P wave from numerous earthquake records two important facts become evident. First, P waves are recorded at all distances up to 103 to 104 degrees (7100 miles), but then they abruptly disappear (Figure 18). On the records of some of the largest earthquakes they continue on to greater distance, but are comparatively very weak. This indicates that there is some type of body within the Earth

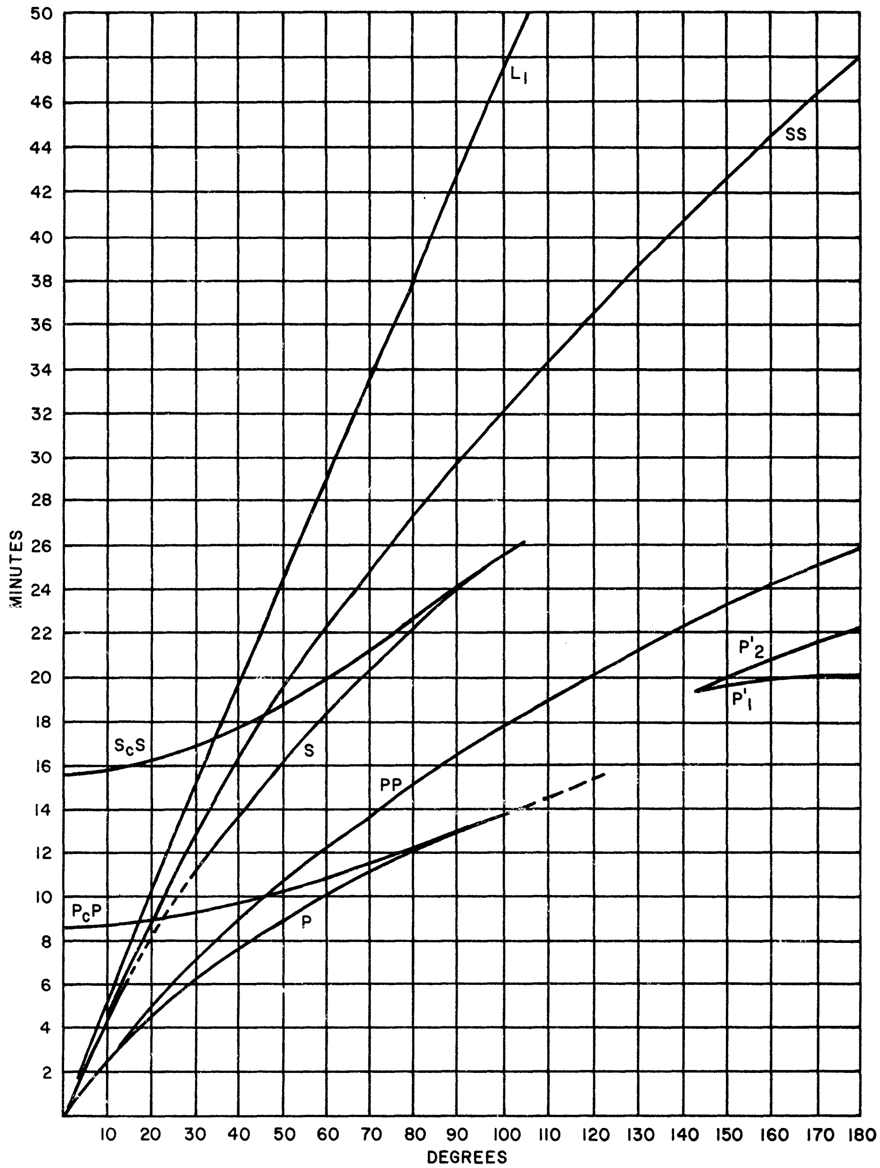


Figure 18 - Graph of travel time for earthquake waves P, PP, P_cP, P'_1, P'_2, S, SS, S_cS, L_1.

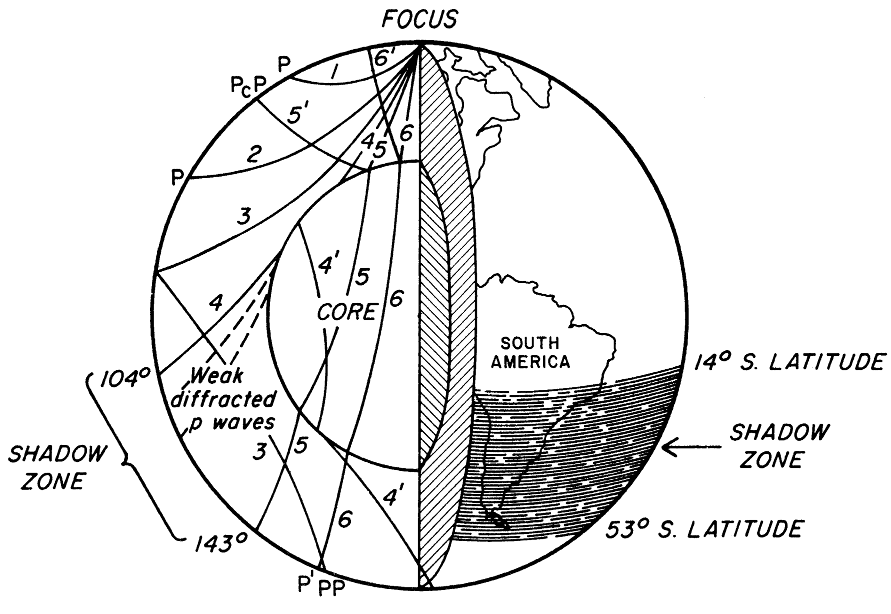


Figure 19 - A shadow zone of an earthquake originating near the north pole. Rays 1, 2, and 3 are high incident waves and emerge at the surface without reaching the Gutenberg discontinuity. Ray 4 just grazes the Gutenberg discontinuity and emerges at the surface 104° from the focus. It is also refracted into the core and emerges 180° from the focus (4'). Rays 5 and 6 are low-incident rays and are refracted into the core; they are also reflected back to the surface by the discontinuity (5' and 6'). (Modified from B. Gutenberg)

that cuts off the waves and prevents them from being transmitted on through the Earth directly (Figure 19). This is the body that we will call the *core.* Second, there are small variations of the plot from a smooth curve at short distances, up to about 20 degrees (1400 miles). If we plot the amplitude of the waves for any single earthquake against the distance we also find variations, particularly at the short distances. The amplitude of the waves is a measure of the energy reaching the surface. In most physical processes that involve the radiation of energy the energy decreases with the square of the distance, but at short distances in earthquakes this is not true. This indicates that there are discontinuities in the Earth at shallow depths that affect the transmission of energy. Actually the P wave almost disappears from the record at 12° (830 miles) and reappears with a very changed character at around 13° (900 miles). This nearly complete disappearance of P is thought to be the result of a *low velocity zone* at a depth of around 60 miles in the Earth. Again the P wave decreases abruptly in amplitude at a distance of 38 to 40 degrees (2600 to 2800 miles). This and other changes of P amplitude around 20° may be due to changes of structure of minerals as a result of pressure.

180° from the epicenter a P type wave is recorded, but it arrives approximately one minute later than it would be predicted from the P velocity at distances up to 104°. This 180° wave has travelled directly along the diameter of the Earth and would not be refracted upon passing through boundaries between contrasting materials. Thus the core of the Earth must have a lower velocity for compressional waves than the material above it. This fact accounts for the disappearance of P waves at 104° because the low velocity core acts as a great lense in the Earth focusing the energy which strikes it into a zone on the opposite side of the Earth. This focused energy appears at an arc distance between 143° and

180° (9870 to 12,420 miles). This focused energy appears as two waves; one called P'_1 which has travelled close to the diameter of the Earth, and the other called P'_2 which has followed a longer path barely hitting the edge of the core on its original path into the Earth. The zone between 104° and 143° is called the *shadow zone* because the low velocity core in effect casts a shadow there preventing direct P waves from reaching that zone.

Seismic waves can be reflected off of interfaces between materials of contrasting velosity in the same manner that light is reflected. There are two important types of reflected P waves. One is a wave which has been reflected off of the core back to the surface. This is called a P_cP wave (P, a compressional wave to the core; c a reflection off of the surface of the core; P, the return to the surface as a compressional wave.) This wave is useful in the original determination of the depth to the core, a distance of approximately 2900 kilometers (1750 miles). This reflective boundary is called the Gutenberg Discontinuity in honor of the seismologist who determined its depth. The major zone of the Earth above the Gutenberg Discontinuity is called the *mantle*. The second important type of reflected wave is one which has been reflected off the surface of the Earth back into the solid body. Such reflections can occur repeatedly giving rise to phases identified as PP and PPP. Many other P phases are possible and known. Each newly identified phase increases the accuracy with which the character of the materials within the Earth can be calculated.

The Family of S Phases

Time-distance plots for the direct S wave again plots as a smooth curve indicating increase of velocity with depth. As in the P wave plot, S is recognizable out to an arc distance of 103 to 104 degrees and again abruptly disappears. Thus the core acts as a shadow cutting off the direct transmission of the waves beyond 104° (Figure 18). The S waves, like the P waves, vary in their amplitude at short distance, and almost disappear at an arc distance of 12°. Unlike the P waves, they do not reappear until around 18° so that the apparent discontinuity at a depth of around 60 miles is much more effective on the S than on the P.

At 180° no direct S type waves ever appear, neither do they appear anywhere in the zone from 143° to 180°. There are thus no shear waves equivalent to the P'_1 or P'_2. Shear waves cannot be transmitted through the core. This has resulted in the interpretation that the core *behaves* as a *liquid* because liquids can transmit compressional waves but cannot transmit shear waves. The 60 mile discontinuity which so strongly affects S waves at distances of 12° to 18° *may* also involve a liquid phase present in the mantle at this depth. If there is liquid at this depth it probably makes up only a minor percentage of the material.

S waves like P waves are reflected off of interfaces between materials of strongly contrasting velocities. The two major reflecting surfaces are the surface of the Earth and the core, so again SS, SSS, and S_cS waves are recorded. SS and SSS have been reflected off of the surface of the Earth once and twice respectively back into the interior of the Earth. S_cS has travelled through the mantle, been reflected off of the core, and returned to the surface through the mantle. Many more complex wave patterns have been identified and each increases the accuracy with which the velocities at each depth can be calculated and the accuracy with which the physical characteristics of mantle materials can be predicted.

P Waves At Short Distances - The Crust

In 1909 A. Mohorovicic, a seismologist in Yugoslavia, was studying a local earthquake and discovered that at distances of 50 to 90 miles the P wave arrived as two distinct pulses. At near distances the first pulse came in with large amplitude and the second with small amplitude. At greater distances in this range the first pulse came in with small amplitude and the second pulse with large amplitude. This indicates that the high amplitude pulse

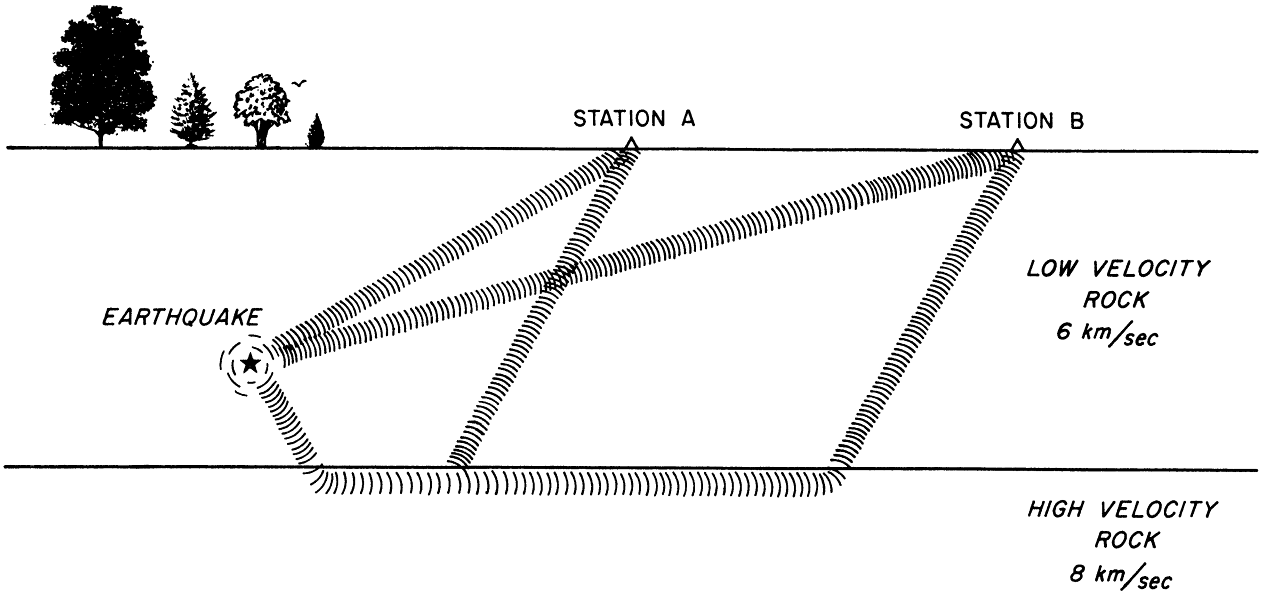


Figure 20 - Mohorovicic's model for earthquake records at short distance. At station A the direct wave from the earthquake would come in before the one which took the longer path whereas at station B the long path, most of it at 8 km/sec., takes less time than the shorter path all of which is at 6 km/sec.

has a lower mean velocity than the low amplitude pulse (Figure 20). Mohorovicic interpreted from this data the presence of a discontinuity at the depth of 18 to 20 miles between low velocity surficial materials and higher velocity basement material. This discontinuity is known as the Mohorovicic Discontinuity (commonly called the Moho) which separates the crust above from the mantle below. The depth to the Moho varies from one region to another, generally with a direct relationship to the regional elevation. Under topographically high regions the Moho is at greater depth. Under the deep oceans it is generally at a depth of six to eight miles below sea level. In the stable interiors of continents, such as the Mississippi Valley region, the Moho is at a depth of twenty to twenty-two miles. Under young high mountains such as the Himalayas, the Moho may be in excess of forty miles below sea level. Under most of Arkansas the Moho is at a depth of around twenty-one miles, but as we go west across the high plains of Western Oklahoma and eastern New Mexico to the front of the Rocky Mountains the Moho gradually deepens to about thirty-five miles below sea level under the Front Range and Sangre de Cristo Mountains. We can visualize the crust as being light rock "floating" on the heavier rock of the upper mantle.

In the modern concepts of sea floor spreading and continental drift, and in the mechanics of the Earth's surface being made up of "rigid" plates which move relative to each other; the plates involved in the concepts include both the crust above the Moho and the upper mantle down to the low velocity zone at a depth of around sixty miles. This relatively rigid plate is called the "lithosphere" and appears to move over the much more plastic mantle material. If the low velocity zone involves a small degree of melting of the mantle materials, as is suggested by the almost total disappearance of the S waves in the 13° to 18° range, this small fraction of melt in the mantle may account for the mobility of the overlying lithosphere.

ZONATION WITHIN THE EARTH

The velocities of seismic waves at all depths within the Earth are now known with reasonable accuracy (Figure 21). If we plot

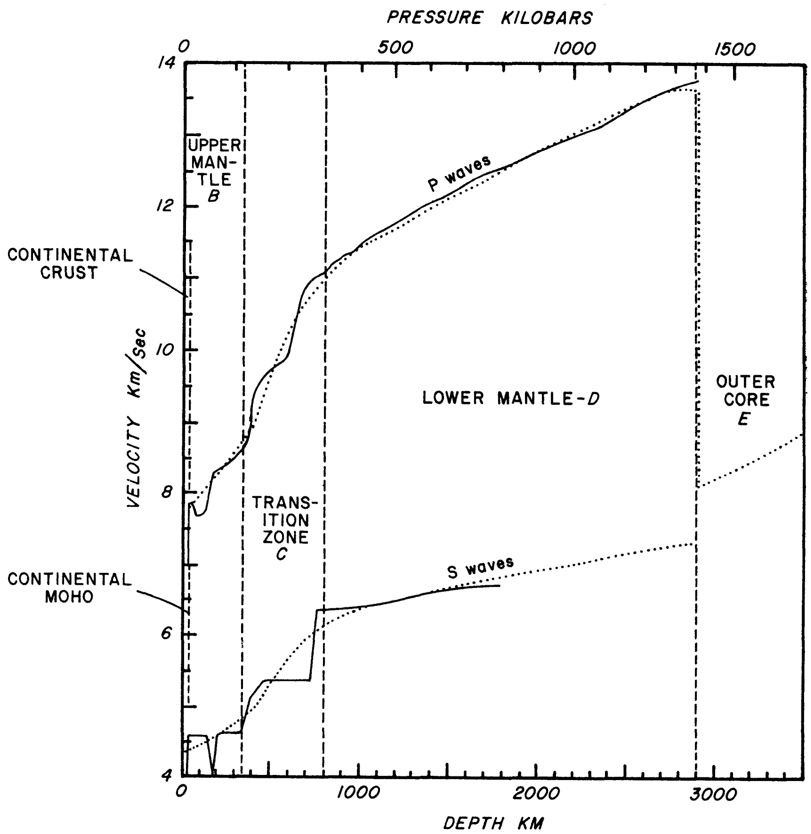


Figure 21 - Seismic velocity distributions in the mantle and mantle zones. P waves—solid line: Johnson (1967, (1969); S waves—solid line: Nuttli (1969); broken lines—Jeffreys (1939).

velocity against depth we develop a curve with rather darked changes of slope at specific depths and on the basis of these changes of slope we divide the Earth into seven major concentric spherical zones (Figure 22). The A zone is that portion above the Moho, the crust. It is very thin in comparison to the total radius of the Earth and variations within this zone are now shown on the Figure. However we can recognize several changes of seismic velocities within this zone and it is commonly subdivided into at least two layers; an upper layer with the seismic velocity of rocks similar to granite, and a lower layer with seismic velocities similar to those of dense volcanic basalts. Thus we speak of the "granite" layer of the crust and the "basalt" layer. This does not intend to imply that these layers are actually these rocks, but physically they behave as these rocks would at these depths. The "granite" layer is important only under the continents and their immediate shallow marine shelf areas.

The Second layer, the B zone, extends from the Moho to a depth of around 400 Kilometers, a depth at which seismic velocities increase rapidly in two steps. The B zone is quite variable in its character both vertically and horizontally. The "low velocity zone" of the upper mantle falls in this zone with higher velocity rocks both above and below it. Further, the velocity data indicates that the character of the rocks above the low velocity zone vary horizontally, the velocity in these rocks is lower under the Rocky Mountains than it is under the Mid-continent area. This means that the rocks themselves are fundamentally different under these two areas. What the differences are is not known; it may be a compositional difference, or it may be a temperature difference in the same type of rock. Eventually the accumulation of more geophysical data may solve this problem.

The C zone extends from a depth of 400

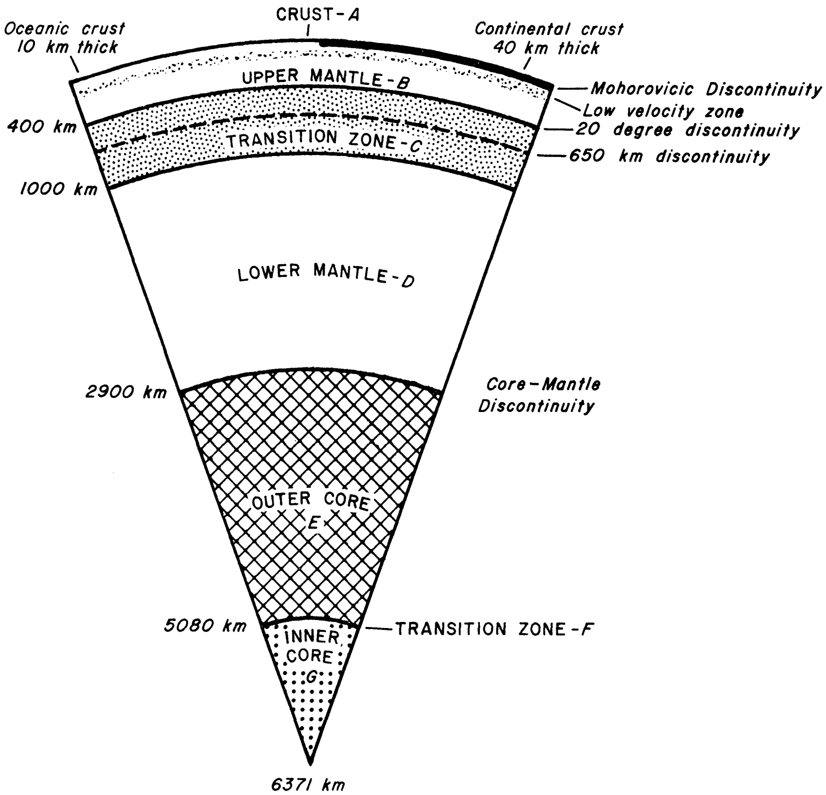


Figure 22 - Principal subdivisions of the Earth.

to 900 kilometers approximately. The evidence indicates that this zone is one in which the rocks which are present at the lower pressures of the lower B zone are undergoing mineralogical changes at constant composition due to the increase of temperature and pressure. The temperatures and pressures at this depth in the Earth can be developed in the laboratory, so that with assumptions as to the chemistry, experiments can be run to duplicate this zone. With what are thought to be reasonable assumptions of chemistry, this zone is one of a change in the crystal structure of the materials to much more dense materials.

The D zone is one of nearly constant increase of velocity of seismic waves. The increase is what would be predicted as a result of temperature and pressure increase. Thus this zone appears to be a homogeneous material. At the base of the D zone, as the core is approached, there is a decrease in the rate of increase of velocity. What changes take place here are completely unknown. It may represent a zone in which there is a mixture of core and mantle material.

The core, beginning at the Gutenberg Discontinuity at about 2900 kilometers, is divided into three zones. The upper, the E zone, behaves as a liquid in that it does not transmit shear (S) waves. There is a marked decrease of the velocity of P waves at this depth. Generally the core is considered to be composed of an iron-nickel alloy by analogy with iron meteorites. In the Earth, if this zone is composed of such material, it probably contains a significant amount of silicon metal in solution and concentrations of other metals which are more stable chemically in a metallic phase than in a silicate or oxide phase.

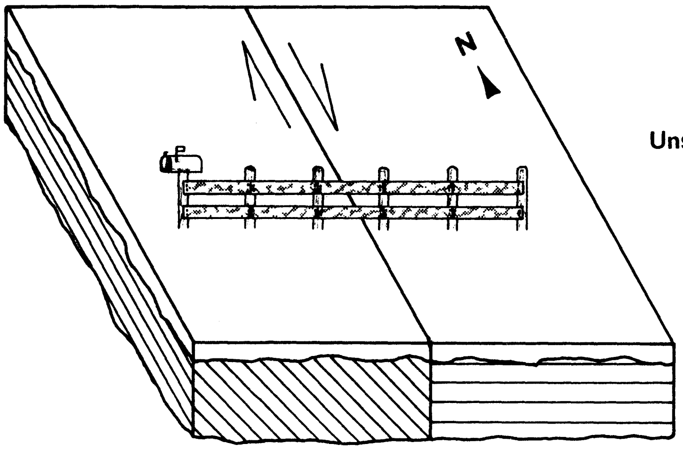
The innermost core, the G zone, appears to behave as a solid. It is surrounded by a thin zone of transition, the F zone, between it and the outer "liquid" core. It begins at a depth of about 5,000 kilometers and extends to the center of the Earth. The evidence of its existence is in the presence of some weak seismic waves which appear in the shadow zone and must have been highly refracted in the core. If the inner core is solid, as it appears to be, and if it has the same composition as the outer core, as it is assumed to have; then this sequence of solid core - liquid core - solid mantle puts very rigid constraints on the temperatures at depth within the Earth. Thus seismic waves allow us to subdivide the inner Earth into zones. The calculated velocities at depth; the calculated physical properties of materials at depth; and the reflection, refraction, and non-transmission of waves at various depths all put marked constraints on our interpretation of the materials of the inner Earth. Temperature in the Earth as measured in wells and deep mines increases at a mean rate of one degree centigrade per 30 meters. At that temperature gradient, if the Earth were composed of rocks like Hawaiian type lavas, the entire Earth below a depth of 36 kilometers would be molten. If it were composed of rocks like stone meteorites it would be entirely molten below a depth of 50 kilometers. Seismic wave data demonstrates that the Earth is solid to a depth of 2900 kilometers. Therefore, either our model of Hawaiian lava rocks or stony meteorites is wrong *or* temperature does not increase at the same high rate at depth as it does at the surface. The boundaries solid inner core - liquid outer core - solid mantle indicated by earthquakes and other data indicates that temperature below a depth of about 100 kilometers increases much more slowly than it does at the surface.

SOLVING EARTHQUAKE SOURCE MECHANISMS

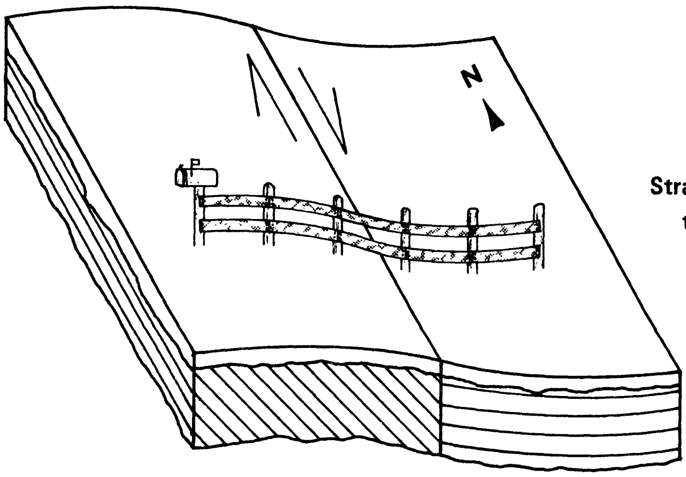
In some of the largest earthquakes, such as the 1906 San Francisco earthquake and the 1959 Hegben earthquake west of Yellowstone, the fractures break through to the surface of the Earth so we can readily see what has happened with respect to the relative movements on the two sides of the fault. However in the great majority of earthquakes, even large ones, no such fracture to the surface develops and the relative motions involved have either to be inferred or in a few cases determined by accurate surveying both before and after the event. How can we, for instance, determine what is happening that causes the numerous small earthquakes that are felt and recorded in northeast Arkansas and southeast Missouri?

Let us assume that there is a fracture which trends north-south and is vertical, and let us assume that there is a slow accumulation of force that is pushing the west side of the fracture northward relative to the east side (Figure 23). Strain will accumulate in the rocks on both sides of the fracture, actually bending them slightly, until the strain in the rocks overcomes the frictional resistance on the fracture. Such fractures in the Earth are not smooth planar surfaces, but rather they are irregular in detail and involve a variety of rocks of varying strength. Therefore slipping will begin at one small area of the fracture and the slipping motion will extend along the fracture rapidly. It is this first motion that we are concerned with. Now, let us construct a line perpendicular to the fracture trace through the point of first motion. This perpendicular and the fault trace divide the area into four quadrants. In the northwest and southeast quadrants the first motion is a compressional wave moving into the area as the rocks involved in the first motion slam northward west of the fracture and southward east of the fracture. In the southwest and northeast quadrants, however, the first motion causes a dilational wave as the rocks are jerked northward west of the fracture and southward east of the fracture. If we have a series of seismometers surrounding the area, those instruments in the northwest and southeast quadrants from the source will record a compressional first motion whereas those instruments in the southeast and northwest quadrants will record a dilational first motion.

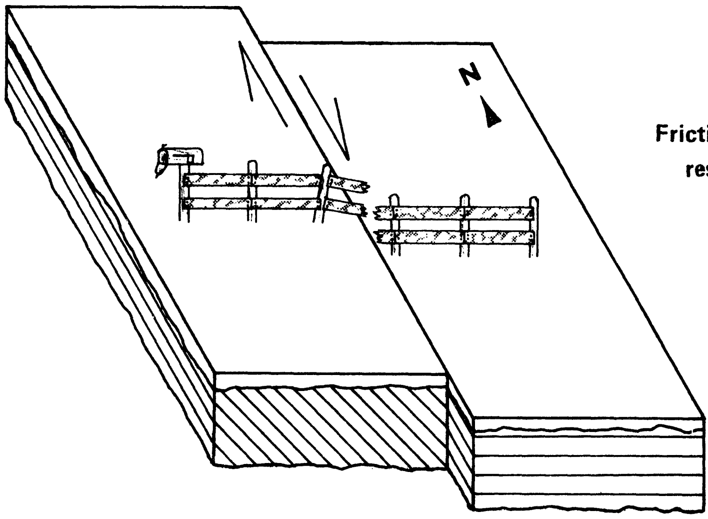
This hypothetical case illustrates how the earthquake focal mechanism is determined. If a particular earthquake is to be studied, first we must collect a large number of station records



Unstrained vertical fracture crossed by a fence.



Strain accumulates by warping the rocks along the fracture.



Friction on the fracture is overcome by strain resulting in abrupt motion; first slip under the fence. Compressive waves are experienced in the NW & SE quadrants and dilational waves in the SW & NE quadrants.

FIGURE 23

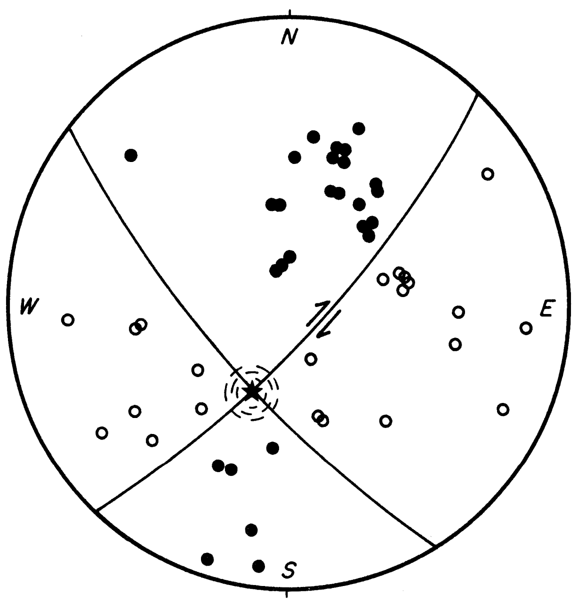


Figure 24 - Determining earthquake mechanism. The epicenter is represented by a ★ ; stations with compressive first motion by ● ; stations with dilational first motion by ○ . The two arcs divide the stations into four quadrants, one of the arcs represents the fault. On the basis of known local geology the NE/SW arc has been selected as the fault with relative motion as indicated by the arrows.

from all directions around the epicenter. The first motion of the P wave is noted from each station deciding whether it is compressional (first motion up on the vertical seismometer) or dilational (first motion down on the vertical seismometer). The location of each station is plotted on a spherical projection with the epicenter of the earthquake at the pole of the sphere. Each station is designated as being compressional or dilational. The stations ideally fall into four quadrants and the quadrant dividing lines can be drawn on the sphere. One of these lines is the trace of the fracture and the other perpendicular to the fracture. Deciding which is which usually requires some detailed knowledge of the geology of the epicentral region, but a choice can usually be made. The point of intersection of the two lines separating the quadrants, and the distribution of compressional versus dilational first motions make an interpretation of the focal mechanism possible (Figure 24).

Such a technique is far easier to describe than to put into practice. It takes a large number of seismic stations appropriately located around the epicenter to be able to draw lines dividing the quadrants with reasonable accuracy. Second, the identification of the same first P wave on each of the records is essential and is difficult. Therefore the number of earthquakes for which a focal mechanism solution has been determined is very small. Fortunately one of the areas for which there are a number of such solutions is northeast Arkansas, southeast Missouri, and up the Ohio River to Indiana. The analysis of 38 earthquakes recorded from this area between 1962 and 1972 show two trends of fracturing. The major trend extends from Memphis, Tennessee along the Mississippi River through the Missouri bootheel and on through extreme southeastern Illinois to the Illinois-Indiana border on the Wabash River. The motion is predominantly north-south as though there is a series of north-south faults lined up on the north-northeast trend. From Memphis into the Missouri bootheel the sense of motion indicates tension in the crustal rocks whereas from the Missouri bootheel on up to Indiana the sense of motion indicates compression in the crustal rocks. The other trend is further west in Missouri along the southeastern margin of the Ozark uplift. Here the sense of motion indicated on the fractures is east-west and predominantly shows tension in the crustal rocks. In the area where the two systems of fractures meet there is considerable randomness in the sense of motions indicating that the two fracture sets are interferring with each other.

Figures 25 - 34 are the seismic records of earthquakes and explosions which exhibit many of the seismic characteristics previously discussed.

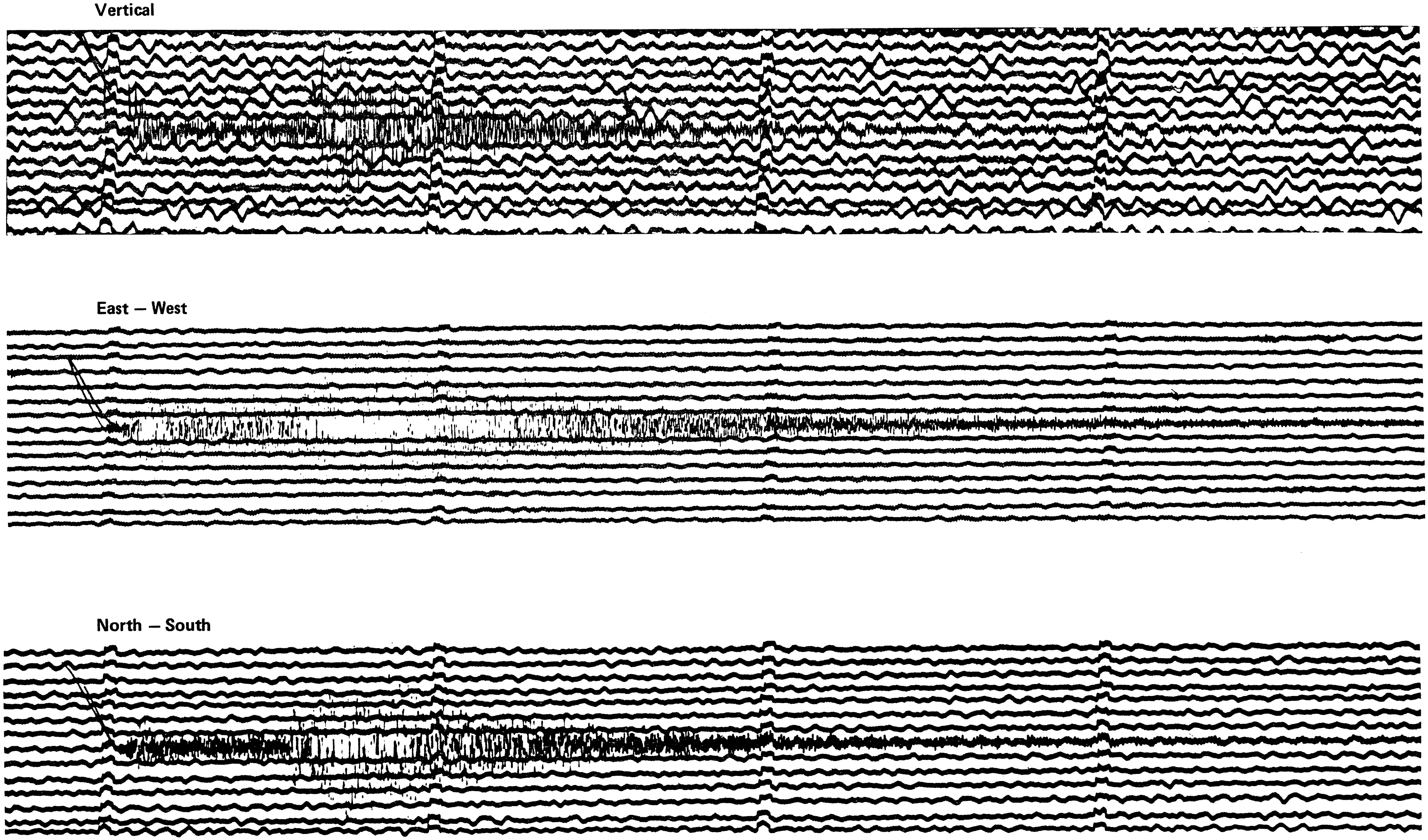


Figure 25 - January 2, 1975 03:18:59.7 CST, Felt at Forrest City, Arkansas, Magnitude 2.9. Begin P phase 09:19:42.4. Note a second P phase arriving about six seconds after the first (refer to Figure 20, this is a station B case). S—P = 36 seconds.

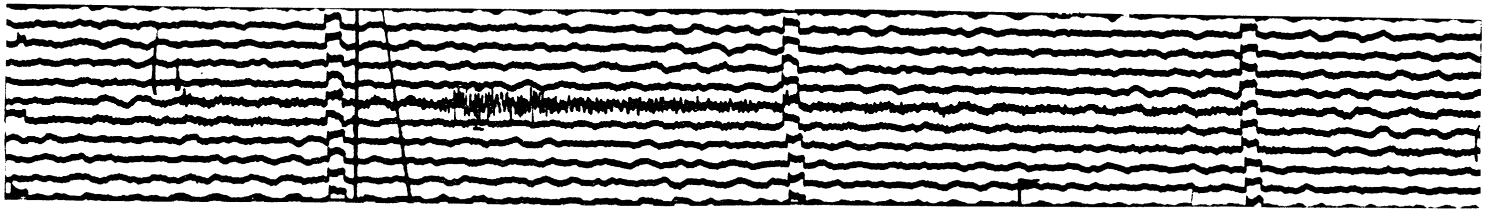


Figure 26 - August 24, 1975 18:44:14.5 Ellington, Mo., Magnitude 2.7, S–P = 39 seconds.

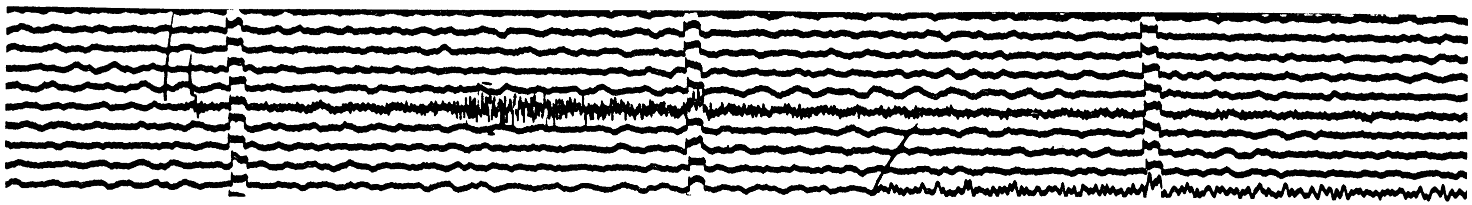


Figure 27 - August 24, 1975 21.01:28.4 Ellington, Mo., Magnitude 2.8, S–P = 38 seconds.

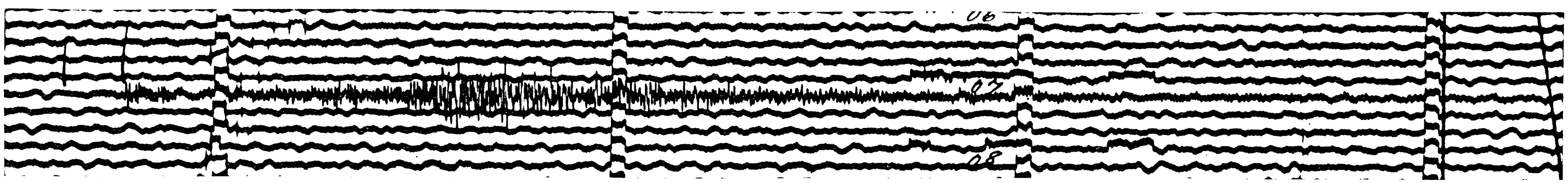


Figure 28 - August 25, 1975 01:11:08.0 Holland, Mo., Magnitude 3.0, S–P = 42 seconds.

Figures 26 - 28 - Three small Missouri earthquakes on August 24 - 25, 1975. Note the marked similarity of the two records from Ellington.

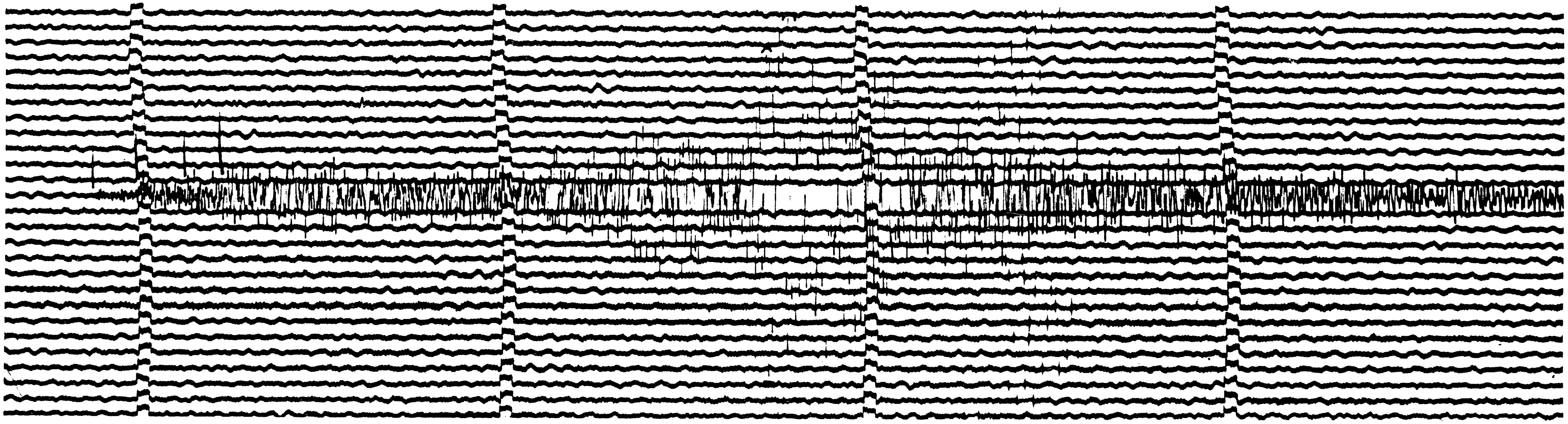


Figure 29 - August 28, 1975 22:22:51.9 CST, Alabama, Magnitude 3.5. S—P = 1 minute, 14 seconds, distance 720 kilometers.

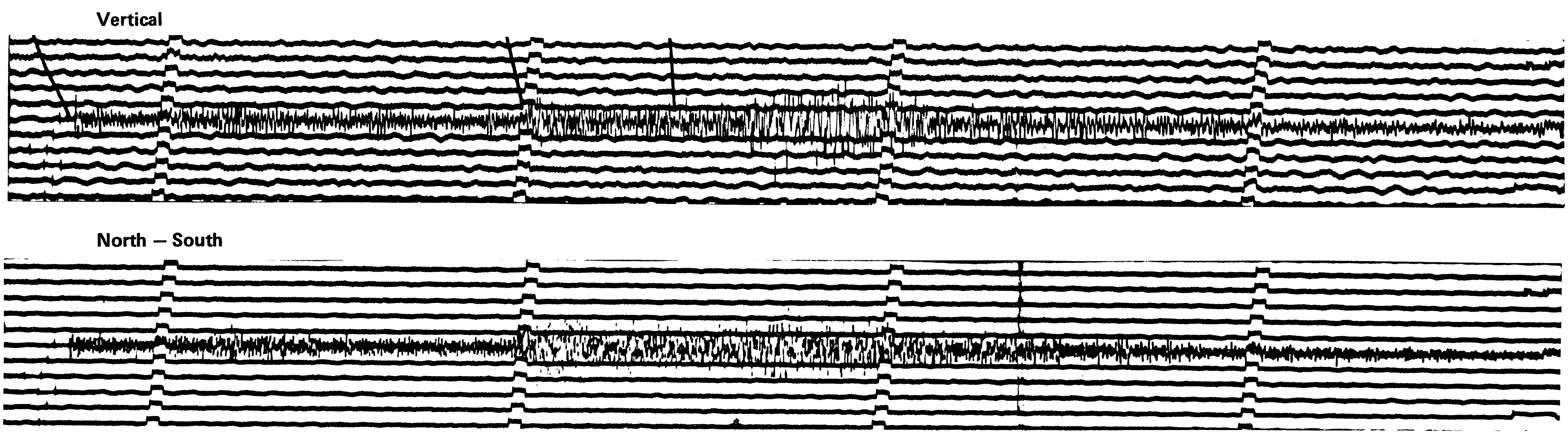


Figure 30 - May 13, 1975 01:53:38 CST, Nebraska, Magnitude 4.3. S—P = 1 minute, 15 seconds, distance 740 kilometers.

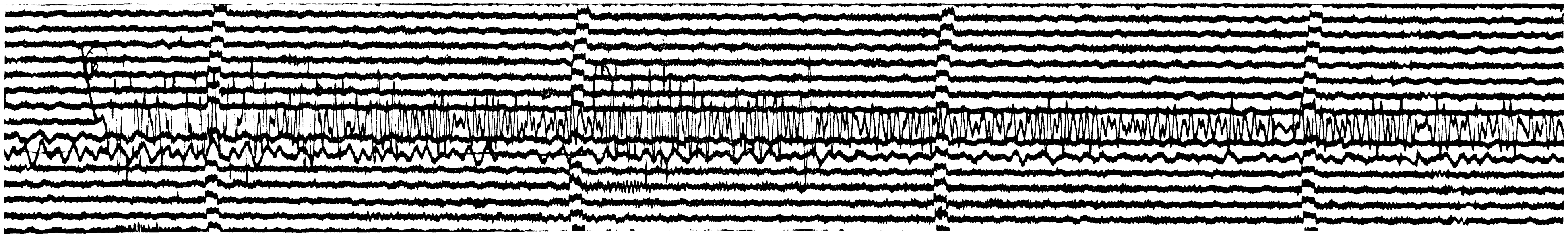


Figure 31 - June 3, 1975 14:20:00.2 Underground nuclear blast. Nevada Test Site, Magnitude 5.9.

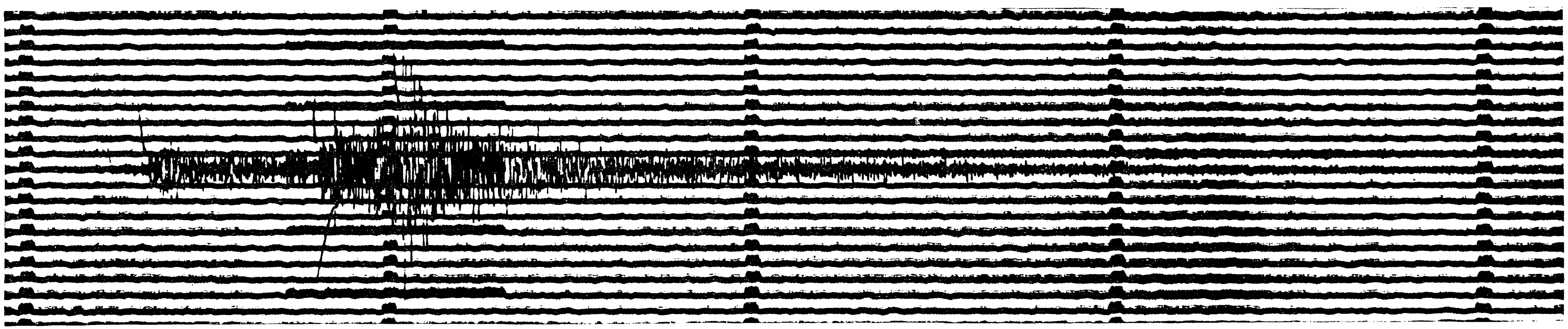


Figure 32 - October 12, 1975 03:47:03.9 CST, Oklahoma, Magnitude 3.2, S—P = 30 seconds, distance 350 km.
Note two P and two S phases. High amplitude waves are L.

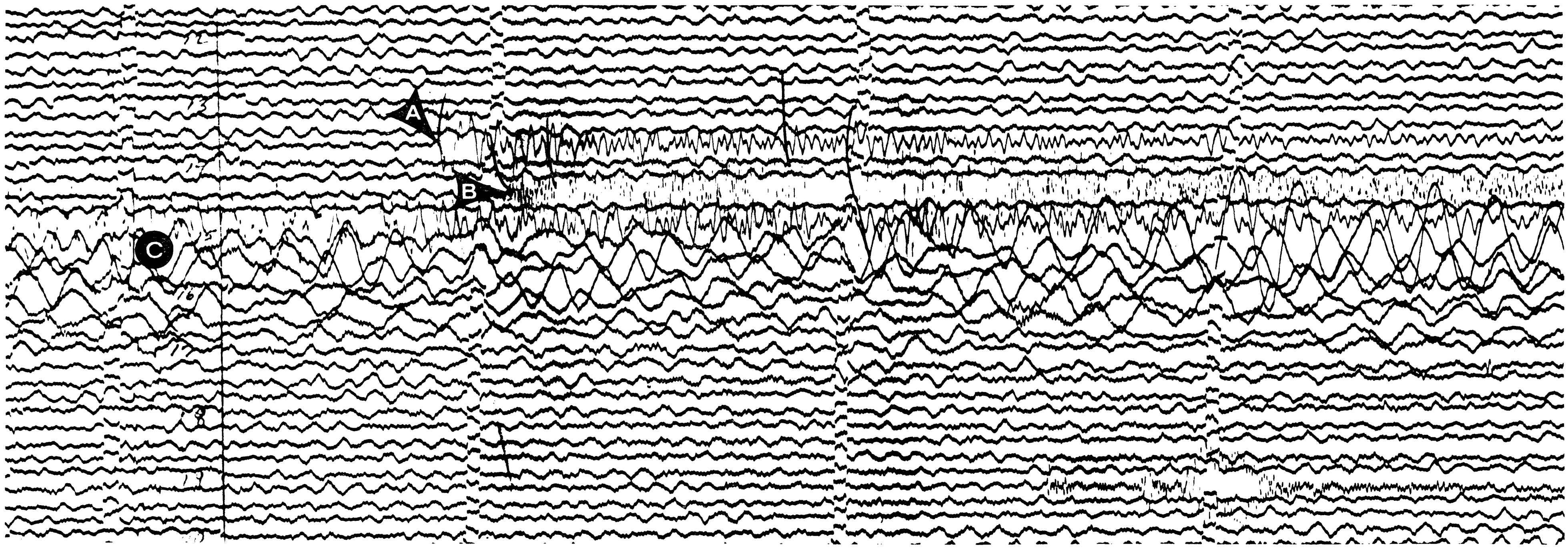


Figure 33 - The problems of interpretation. November 29, 1975. Event A was a Magnitude 5.8 earthquake originating in Hawaii. Event B was a 3.5 tremor epicentered in Oklahoma. Event C was a major Hawaiian earthquake of Magnitude 7.2; two killed, four million dollars in damage.

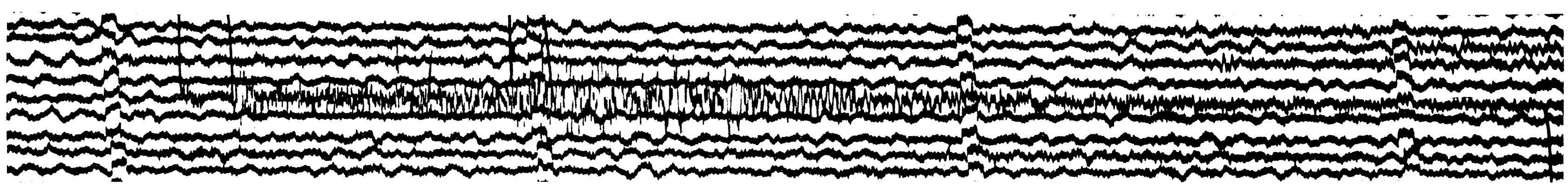


Figure 34 - January 10, 1975 09:31:00.8 CST, Pea Ridge Mine, Mo.; 300,000 pounds gelignite blast. Begin first P phase 15:32:00.0, distance 400 km. Note two P and two S phases marked. S—P = 46.5 seconds.

SEISMIC BELTS OF ARKANSAS AND NEIGHBORING STATES

Six seismic belts can be more or less defined in Arkansas and the contiguous states (Figure 35). The most active is in the New Madrid area. In reality this name implies a much too restricted area as the active belt extends along the Mississippi, Ohio, and Wabash Rivers into Indiana and beyond. Therefore this belt will be referred here to as the Mississippi-Wabash Belt. A second trend in Arkansas approximately parallels the boundary between the Ouachitas and Ozarks to the north and west and the Mississippi Embayment and Gulf Coastal Plain to the east and south. This will be referred to as the Fall Line Belt. A third and comparatively inactive trend extends across the northern Ouachita Mountains and related folded rocks south of the Arkansas River. This will be referred to as the Frontal Ouachita Belt. Westward in Oklahoma, Kansas and Texas there are two belts one of which has resulted in earthquakes which have been felt in Arkansas. This is a belt that extends south-southwest across Kansas from the Iowa border to central Oklahoma, and then south toward Texas. It is known as the Nemaha Belt. The second extends across southwest Oklahoma and the panhandle of Texas. It is associated with a series of partially buried to completely buried mountainous ridges and adjacent sediment filled basins. The old mountains are known as the Wichita and Amarillo Mountains. No earthquakes from this belt have been felt in Arkansas. Finally the eastern margin of the Ozark Plateau in Missouri is a seismically active region which is distinct from the Mississippi-Wabash Belt in spite of the fact that the two overlap. This region will be referred to as the Southeast Missouri Region.

The Mississippi-Wabash Belt

A glance at a map will show that the general trend of the Mississippi River from about Arkansas City, Arkansas to Cairo, Illinois is an overall straight line trending about east - northeast. This same trend continues up the lower Ohio River and the lower Wabash River along the Illinois-Indiana border. This trend is not accidental but rather these rivers follow a major fracture zone in the Earth's crust which is one of the two most active seismic zones east of the Rocky Mountains. The other is likewise traceable very easily by observing the straight line pattern of the St. Lawrence River and the lower Great Lakes. Major earthquakes have occurred along the Mississippi-Wabash trend, the most famous being the New Madrid quakes of 1811-1812. Two other large events from this belt occurred in 1843 and 1859. Smaller events are very numerous in this region and fully two thirds of the events listed in this Circular originated here.

The 1811-1812 New Madrid quakes were clearly not a unique series of events. The Indians of the area had traditions of earlier severe shaking and physical evidences, still visible at the beginning of this century, confirmed these traditions. In 1904 trenches identical to those produced in 1811 were recognizable in which 200-year old trees were growing. Similarly an uplifted dome near Blytheville is similar to domes uplifted in 1811 but shows effects of erosion by the Mississippi River at some earlier date. Thus the New Madrid was not a unique event and a similar earthquake probably will occur again in the region.

A series of small earthquakes extending from Memphis, Tennessee to Mt. Carmel, Illinois on the Wabash have been studied in detail from instrumental records by Street, Herrmann and Nuttli (1974). They found that the attitude of the fractures indicated by the majority of the eighteen events was approximately north-south although the trend of the belt is north-northeast. From the middle of the Missouri bootheel southward in Arkansas and Tennessee the sense of motion indicated tension in the crust. In contrast events north of the bootheel of Missouri, in Kentucky and in Illinois indicated compression in the crust. This complex pattern suggests that many of these small events are adjustments on

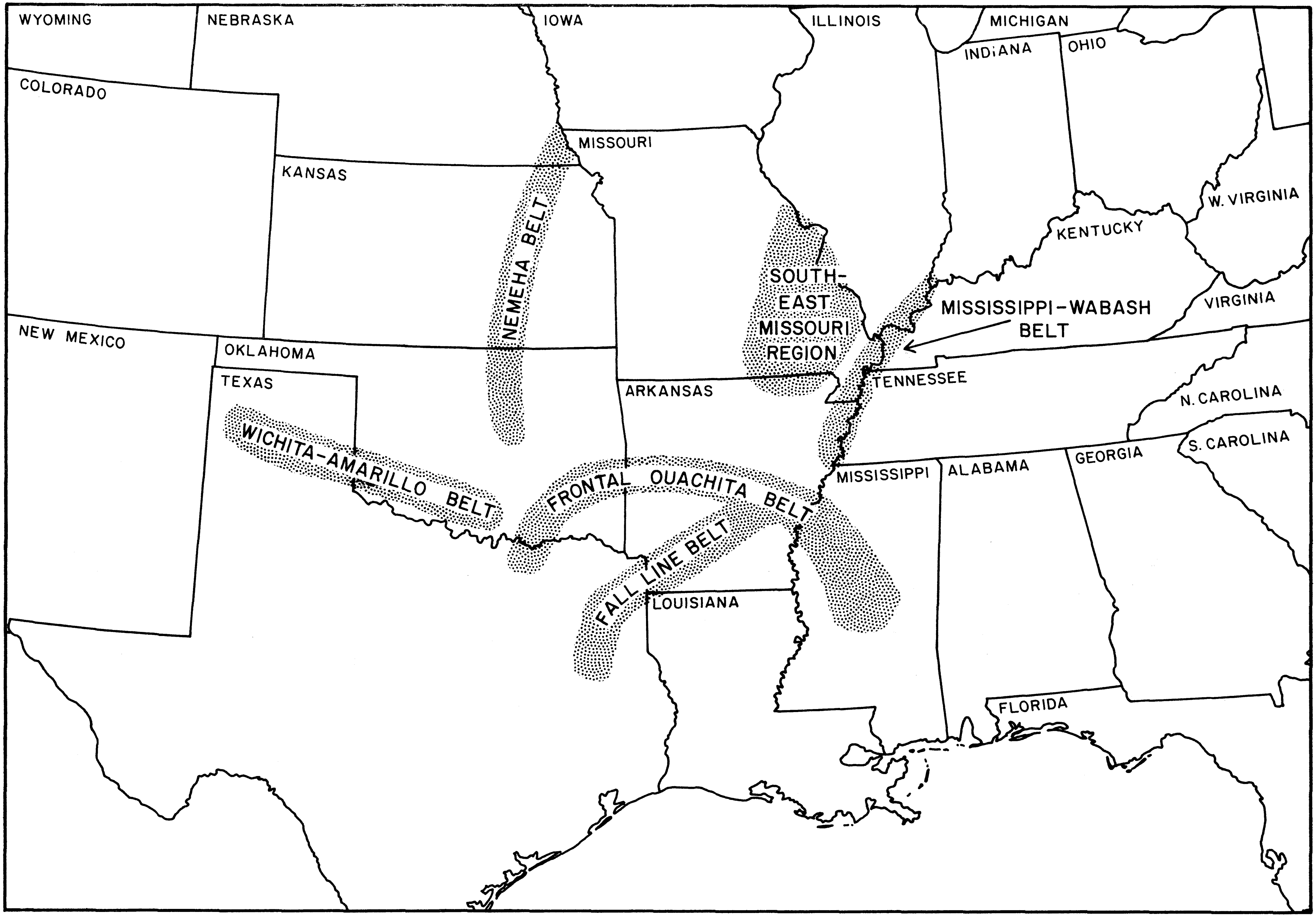


Figure 35 - Seismic regions.

secondary north-south fractures overlying the major fracture. In contrast the reconstruction of the 1811-1812 earthquakes on physical grounds indicates movement on the major north-northeast fracture. Perhaps only major events are the result of movement on the deep-seated major fracture.

The Fall Line Belt

The term "Fall Line" was first applied to the eastern seaboard of this country where rivers coming out of the folded crystalline rocks of the Appalachians went over a series of rapids and falls in descending onto the soft younger sediments of the Atlantic Coastal Plain. The term is used here in a similar sense in that this belt roughly follows a similar boundary to the southeast and south of the Ouachitas. Earthquakes which are a part of this belt include at least some of those near Little Rock and Pine Bluff; those south of Arkadelphia; and westward into Oklahoma including those near Broken Bow, Idabel, and Hugo. The earthquakes in 1957 between Tyler and Lufkin, Texas may belong to this belt.

The Paleozoic Ouachita Mountains were beveled on the south and east by erosion under the Mesozoic seas. This old platform has been bowed downward so that just south of the western part of the Arkansas-Louisiana border there is in excess of 12,000 feet of Mesozoic and Cenozoic sediments piled on the basement. To the east of Little Rock the Ouachita range has been obliterated by erosion and buried under younger sediments. The earthquakes of this belt are probably related to modern readjustments along this downwarp of the beveled basement.

Further south in Arkansas there is a trend of young faults which have been active from late Mesozoic to very recent times. These faults extend in a south facing arc from Miller County through Nevada and Ouachita Counties and appear to leave the state in southeast Union County. This trend is often called the Arkansas Graben System and consists of a series of blocks a few miles wide and up to a few tens of miles long which have been dropped on pairs of faults like a keystone block in an arch. This fault system overlies the northern limit of an extensive salt bed. At the grabens in northern Lafayette County the salt is at a depth of about 8,000 feet and is probably in the neighborhood of 700 feet thick. At these depths salt behaves as a very plastic material and the grabens are probably the result of slow plastic flowage of the salt. Only one earthquake in the lists is in the area where salt flow would be the cause. It is the small event south of El Dorado which occurred June 19, 1939.

The Frontal Ouachita Belt

The arbitrarily selected north margin of the Ouachita Mountains in Arkansas is defined by a fault system that extends in a south facing arc from North Little Rock to Y City (the intersection of highways 71 and 270). It extends westward into Oklahoma where it turns southwest and is buried under younger rocks south of Atoka. East of Little Rock the eroded and buried trend of the Ouachitas can be traced by deep drilling southeast across Mississippi. Faulting along this trend is old and complex but with a predominant sense of compression from the south. The folding and some faulting extends further north and is still quite evident as far north as the Arkansas River in western Arkansas and eastern Oklahoma.

A number of earthquakes appear in the list which are related to this trend. The January 1, 1969 event at Ferndale, Arkansas is the only one for which there is sufficient instrumental data to solve a mechanism. Street, Herrman, and Nuttli (1974) find an essentially east-west fault with compression in the crust. The only other event in Arkansas which would belong to this belt is that of 1882. Several small events in Oklahoma may be related.

These include the Antlers event of 1956 and several at Hartshorne. The earthquake northeast of Greenville, Mississippi on June 4, 1967 has been interpreted by Street, et. al., as being on the subsurface eastward extension of the Ouachita front. There have been several other small events in that area of Mississippi.

Earthquakes occurring in the area between Little Rock and Pine Bluff present a special problem in assessing. In this area three recognizable belts cross. It is near the southern limit of the Mississippi-Wabash Belt, it is on the Frontal Ouachita Belt, and it is along the Fall Line. Therefore in order to assess the possible origin of any one event in this area it would be essential to have a good instrumental determination of the fracture attitude and sense of motion. No earthquake from this area has been studied in detail.

The Southeast Missouri Region

The eastern margin of the Ozark dome is sharply separated in southeast Missouri from the adjacent basins to the east. The transition is marked by a series of faults some of which are still active and result in earthquakes. The seismic belt extends from near St. Louis south-southwest to Poplar Bluff, Missouri and expands to the west. It includes some of the small earthquakes in north central Arkansas such as Salem 1883 and Ravenden Springs 1961.

The study by Street, Herrmann and Nuttli (1974) included thirteen minor events in this area between 1962 and 1973. Again, these were recorded instrumentally and many were not felt. The majority of these indicated an east-west trend of the faults with the predominant sense of motion indicating tension in the crust. A few, however, indicated compression in the crust. The minority of the earthquakes indicated a northwest-southeast trend and both compression and tension in the crust. John R. Gibbons studied the structure of a portion of this area as a doctoral dissertation for Syracuse University. His analysis of the fracture patterns indicated faults with the same trends found by Street, et. al. The faults are a type called up-thrusts. These faults are nearly vertical at great depth, but as they approach the surface they curve to about a 45° attitude with a relative motion which would result from compressional forces. This leaves the overriding block at shallow depths unsupported and it collapses along a secondary series of faults which would appear as tension in the shallow crust. Thus the presence of both compressional and tensional affects is compatible with known structure of the area.

The Nemaha Belt

The 1952 earthquake at El Reno, Oklahoma and its aftershocks represent the major recent activity in this belt in Oklahoma. The major shock of this series was felt in Arkansas, but the aftershocks were not, neither were other earlier events in 1918, 1929 and 1933. A small earthquake near Enid, Oklahoma in January 1973 and one near Norman, Oklahoma in December of 1974 belong to this trend as do several events near Manhattan, Kansas and in southeastern Nebraska. Earthquakes in this belt are apparently related to an ancient fault controlled structure buried under a thick column of younger sediments. The structure begins in southeastern Nebraska and extends south-southwest across Kansas passing just east of Wichita. In southern Kansas it turns south and extends across Oklahoma through Oklahoma City. Further south its trend is lost as the trend of the Arbuckle and Wichita Mountains is approached. This structure is called the Nemaha Ridge or Arch (Figure 36).

This structure has been encountered in deep drilling for oil and gas in Kansas and Nebraska. Along the axis of the structure the late Paleozoic rocks (Pennsylvanian in age) rest directly on an eroded surface of old granite. East and west of the axis the same

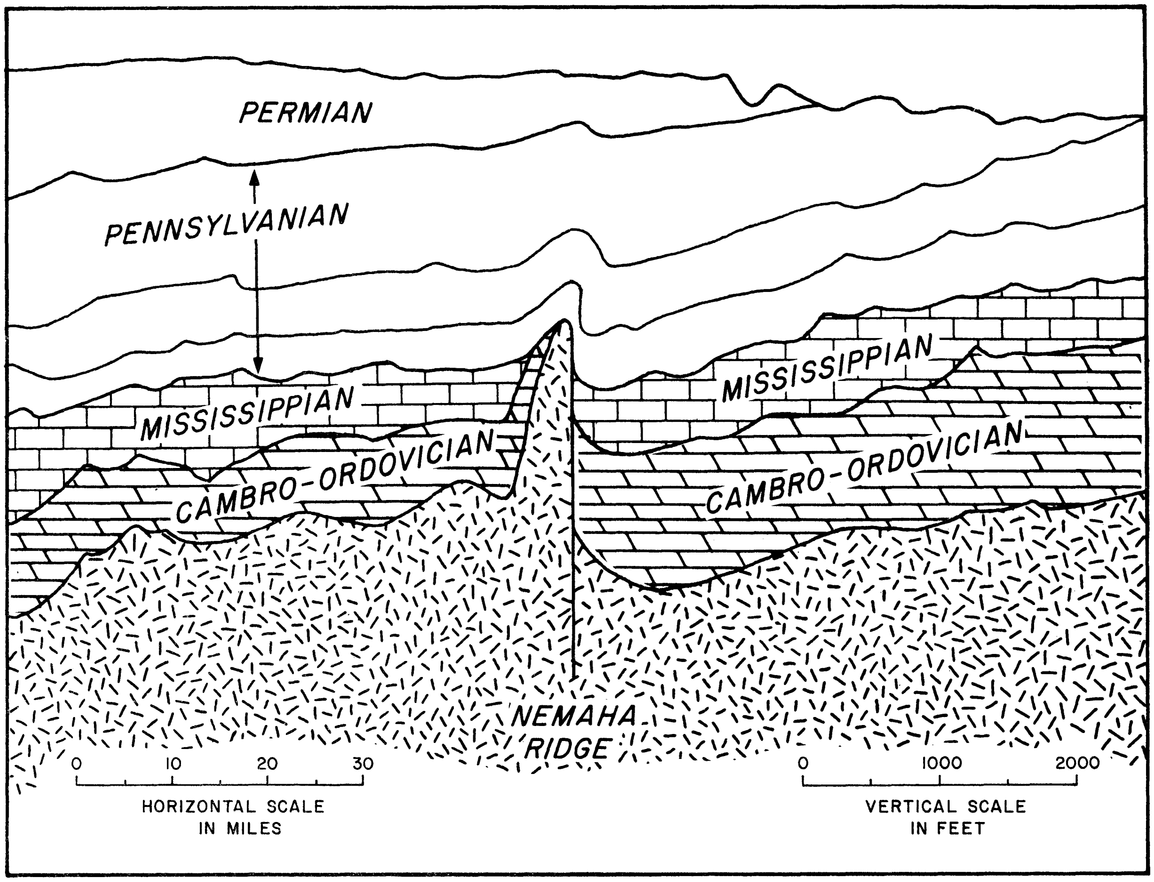


Figure 36 - Cross section of the Nemaha Arch.

Paleozoic sediments rest on the eroded edges of the older Paleozoic sediments, which were originally continuous across the axis. The data indicates that the arch was uplifted, probably in Mississippian time, as a long narrow mountain belt probably bounded by faults. Faults are mappable on one side of the ridge from the well data. The ridge was rapidly destroyed by erosion and buried under the younger sediments. Modern day readjustments on the old faults are the origin of this seismic belt.

The Wichita - Amarillo Belt

The Wichita Mountains of Oklahoma are the only exposed portion of an old mountain chain that extends from southeast of Ardmore west-northwest across southern Oklahoma and the panhandle of Texas. The rest of the chain is buried under younger sediments. The mountain block is bordered by faults on both sides and deep sediment filled basins occur to both north and south. Several earthquakes have been felt in this region, but none of them have been felt in Arkansas. An earthquake on July 30, 1925 in the panhandle of Texas was felt from Roswell, New Mexico to Tulsa, Oklahoma. The events from the eastern end of the region have all been small, the most recent on September 30, 1975 near Ardmore, Oklahoma. A larger event from the Ardmore area would probably be felt in western Arkansas.

THE NEW MADRID EARTHQUAKES 1811 - 1812

The great events in southeast Missouri and northeast Arkansas of 1811-1812 are generally known as the "The New Madrid Earthquake", probably the greatest earthquake of historical times in North America. The following discussion of this series is taken from U. S. Geological Survey Bulletin No. 394 by Myron J. Fuller, published in 1912.

Fuller's report was based on field examination of the area in 1904 and 1905, over 90 years after the event, but the effects were still plainly evident. Fuller's report makes use of all the older records and writings available and the reader is referred to that bulletin for greater detail.

One or more of the eight major shocks was felt at widely scattered points covering all of the United States east of the Rocky Mountains. Most of the felt effects were reported from cities along the major rivers or along the Atlantic Coastal Plain. This may be in part due to the location of population centers in those areas, but that is only a partial explanation. Daniel Drake of Cincinnati, Ohio in describing the effects there says,

> "It was so violent as to agitate the loose furniture in our rooms, open partition doors that were fastened by falling latches, and throw off the tops of a few chimneys in the vicinity of the town. It seems to have been stronger in the valley of the Ohio than in adjacent uplands. Many families living on the elevated ridges of Kentucky, not more than twenty miles from the river, slept during the shock; which cannot be said, perhaps, of any family in town." (Fuller, p. 16)

This statement is probably applicable to much of the eastern United States and to much of Arkansas. The Kentucky hills are an area in which solid bedrock is overlain by a thin layer of weathered rock and soil. In contrast the Ohio valley floor is underlain by a deep blanket of water saturated unconsolidated river gravels, sands and clays. Such thick saturated sediments amplify the effects of the seismic waves and result in much greater shaking and damage than is experienced in areas where bedrock is close to the surface. In much of Arkansas even the largest shocks of the 1811-1812 quakes probably caused no damage and would not have been felt by many persons. The area north and west of an arc from Nashville through Arkadelphia and Little Rock to Pocahontas is an area of thin soil cover on bedrock, except immediately along the major rivers, and little felt effects would have been experienced. The area south and east of that arc would have experienced greater effects and might have sustained damage.

The most complete chronology of the New Madrid earthquakes was kept by Jared Brooks of Louisville, Kentucky. He set up a series of swinging pendulums of various lengths and weighted springs to show ground movement at Louisville. Between December 16, 1811 and May 5, 1812 he catalogues 1,874 separate events that he detected (Table 1). His tabulation given by Fuller (pp 22-26) reads as follows for the week January 27 to February 2, 1812.

Jan.	27	Morning	strong tremor
		8:50 AM	violent
	28	9 to 12 AM	frequent vibrations
		9 PM	slight tremor
	29	9 to 11 AM	incessant slight tremors
		11:30 AM	considerable
	30	9 to 12 AM	barely perceptible
		3 PM	strong tremor
	31	9 to 12 AM	continual tremor
		PM	considerable tremors
Feb.	1	9 AM to 1 PM	tremors and vibrations
	2	2 AM	considerable shock
		9 AM to 12 AM	less than usual
		12 to 10 PM	slight motion
		10:45 to 11:30 PM	frequent slight tremors

On each of Brooks' entries the weather conditions at the time were recorded because at that time there was thought to be a connection between earthquakes and weather. No correlation was found on analysis of his data. The frequency of nearly continuous motion recorded in the forenoon is probably a function of

End of Week		Rate						Total
		Ist	2nd	3rd	4th	5th	6th	
Dec.	22	3	2	3	1	12	66	87
	29	–	–	–	–	6	150	156
Jan.	5	–	1	2	9	3	119	134
	12	–	1	–	10	–	150	161
	19	–	–	–	4	6	55	65
	26	1	1	7	2	2	78	91
Feb.	2	1	–	4	6	7	191	209
	9	3	5	7	5	15	140	175
	16	–	–	3	6	12	65	86
	23	–	–	4	6	4	278	292
Mar.	1	–	–	1	4	8	126	139
	8	–	–	2	9	8	39	58
	15	–	–	2	3	6	210	221
Totals		8	10	35	65	89	1,667	1,874

Table 1 - The weekly listing of New Madrid events by "Rate" of Jared Brooks 1811-1812. The eight first rate shocks occurred on December 16, January 23, January 27 and February 7.

when Mr. Brooks was free to watch his instruments rather than when motions actually occurred. Apparently when he was away from his pendulums they made marks, but no time could be recorded unless the motion was obviously felt.

Mr. Brooks classified his recorded events into six levels. His classes are suggestive of the subsequently developed Rossi-Forel intensity scale, but include a final lowest class which were recorded by his pendulums but not actually felt. His classes as follows are abbreviated from Fuller (p 33).

First Rate. Most tremendous, so as to threaten the destruction of the town . . . buildings oscillate largely and irregularly . . . walls split . . . chimneys, parapets . . . break and topple to the ground.

Second Rate. Less violent but very severe.

Third Rate.	Moderate but alarming to people generally.
Fourth Rate.	Perceptible to the feeling of those who are still . . .
Fifth Rate.	Not defined.
Sixth Rate.	Although often causing a strange sort of sensation . . . the motion is not to be ascertained positively, but by the vibration of other objects placed for that purpose. (pendulums)

The loss of life as a result of these earthquakes was very minor, due primarily to the low population density. A similar event today would undoubtedly take a heavy toll from St. Louis to Memphis and possibly along the lower White and Arkansas Rivers. Only one person can be definitely established as having died on land during these events, and that one was a woman who ran until exhausted and died of fright. The cabins of the country and the frame houses of the towns were such as to give under the shocks and only falling chimneys were a real source of danger. An unknown number of people died on the Mississippi River as a result of bank caving, disappearance of islands,and swamping of boats. The position of the channel of the river was extensively altered by the banks slumping, disappearance of old and development of new islands and bars, and extensive changes of snags on the bottom as innumerable trees were washed into the river. Shipping on the river was hazardous for many months until new channel patterns became established and known.

The physical affects on the ground can be assigned to four types; landsliding or slump, uplift and depression, fissuring, and sand and water extrusion. Landsliding was confined to the river banks and to the bluffs east of the Mississippi River. The Chicasaw Bluffs rise above the river bottomlands in Kentucky and Tennessee. The Bluffs have been developed on a blanket of wind blown dust (loess) which had accumulated on top of older flood plain deposits. Over a distance of fifty miles from Hickman, Kentucky to the mouth of the South Fork River southwest of Dyersburg, Tennessee the bluffs failed by slumping. Slumping involves the development of a curved fracture behind the bluff and movement of large blocks downward and outward along those fractures. Smaller scale slumping occurred along the river banks.

Uplift and depression of the land was quite widespread throughout the Missouri bootheel and southward to about Marked Tree, Arkansas. Scattered areas of elevation change occurred further north in Missouri. The best line of evidence to indicate these changes (that was clearly evident to Fuller in 1904) was the uplift of swamp-land trees, such as cypress, and the drowning of upland trees such as oak and hickory. This type of evidence indicated local subsidences of up to twenty feet and local uplift of an equal magnitude. The most famous of these areas is just east of the Mississippi River at the Tennessee-Kentucky border where Reelfoot Lake still occupies a depression formed during the earthquakes. West and south of Reelfoot Lake is an uplifted area, the Tiptonville Dome, also a result of these disturbances. The stumps of dry-land trees still stood in Reelfoot Lake and the channels of the old drowned bayous could be followed under twenty feet of water.

In Arkansas and Missouri the most extensive depressions were the sunk-lands along the St. Francis and Little Rivers. In 1904 Lake St. Francis and the Hatchie Coon Sunk Lands was a lake forty miles long averaging about a half mile wide. Water stood two to ten feet deep over old channels. On the Little River, Big Lake, between Blytheville and Manila was the largest sunk land. Extensive drainage and channelization throughout the area since 1910 has almost obliterated these lakes, but the Big Lake Wildlife Refuge and the St. Francis Sunken Lands Wildlife Management Area are the remnants. During spring floods much of the old sunken lands return to their former state in spite of levees and drainage ditches.

Fissuring was extensive. The eye witness accounts describe waves traveling over the surface of the ground up to five feet high. The wave crests ruptured to form open fissures a few inches wide and extending to depths of twenty feet. This type of fissuring developed where stronger clay-bound river sediments rested on clean water saturated sands. Such fissures were a few yards to one-to-two-hundred feet long. It was this type of fissure which resulted in sand and water extrusion. A second type of fissure was common in areas near streams and resulted in the development of trenches a few feet wide and deep and three-to-five-hundred feet long. These resulted from the horizontal flow of the lower water saturated sand toward the stream channel. As this flow took place the overlying clay-bound sediments were carried along as a unit slab. Such a slab cannot be stretched without breaking and at the zone of rupture a block was dropped into the fracture zone creating the trenches.

Sand and water extrusion was exceptionally abundant in an oval area between Crowley's Ridge and the Mississippi River from Marked Tree, Arkansas to Sykestown, Missouri. Over much of this area a nearly continuous blanket of sand covered the surface. The early writings reported the sand to be as much as two feet deep and over much of that area the sand blanket smothered the vegetation and rendered the land sterile. In 1904 the sand was still quite evident as low circular mounds of linear patches. The sand, and water which brought it up, was derived from a water saturated sand zone a few tens of feet below the surface. In that zone the sand grains were not as close together as possible before the shaking so that when the earthquake vibrations came the sand grains moved closer together expelling the water. Fissuring of the surface allowed the excess water to escape upward and as it flowed it carried sand with it. The circular mounds, often with broad shallow craters, developed where the main expulsion of sand and water was up a small cyclindrical vent whereas the linear mounds developed where the fissure was elongated. Much organic material (lignite) was brought up with the sand along with pyrite (iron sulfide). These materials were probably the source of much of the sulphurous odor which was reported by the survivors.

In areas where extrusion took place in 1811-1812 which have subsequently been eroded, the fissures may be exposed filled with sand called clastic dikes. In the southern part of the area where sand was extruded, sand sloughs were developed where the trench-like fissures were developed along streams and sand was extruded along one or both of the marginal fractures of the trench.

The surface effects seen seem to be entirely the result of flowage in the unconsolidated sediments at shallow depth. The Mississippi Embayment consists of a trough of relatively young unconsolidated to semiconsolidated sediments which extends from the latitude of Little Rock to Cairo, Illinois. The deepest part of the trough is along the Mississippi River and in Arkansas ranges from 2,000 to 3,500 feet deep. These sediments thin both to the west in Arkansas and to the east in Tennessee to the line where the older consolidated sediments are at the surface. Flowage of the young sediments down slope toward the axis of the trough during the violent shaking of these earthquakes readily accounts for the changes of elevation observed. If faults in the deep crust did extend up to the top of the basement rocks, the displacements were absorbed by flowage of the young sediments in the upper 2,000 feet of the trough. Faults in this type of young unconsolidated material are well known, but motion on them is not accompanied by earthquakes. The Gulf Coast from Houston, Texas into southwest Louisiana is subject to such faulting at the present time.

TABLE 2

LIST OF EARTHQUAKE TREMORS

Year	Date	Time CST	Latitude	Longitude	Intensity	Magnitude	Location from Latitude & Longitude	Felt area sq. mi.
1843	Jan. 4	21:30	35.2	90.0	8		Memphis, Tenn.	Max. probably New Madrid
1865	Aug. 17	9:00	36.5	89.5	7		South of New Madrid	Felt, 24,000
1878	Nov. 18	11:52	36.7	90.4	6		Poplar Bluff, Mo.	Felt, 150,000
1882	Oct. 22	16:15	35	94	6 - 7		Between Waldron & Booneville, Ark.	Felt, 135,000
1883	Jan. 11	1:12	37.0	89.2	6		Cairo, Ill.	Felt, 80,000
1883	June 11	12:16	35.2	90.1	6		Three shocks, Memphis, Tenn.	Local
1883	April 12	2:30	37.0	89.2	6 - 7		Cairo, Ill.	
1883	Dec. 5	9:30	36.3	91.8	5		Salem, Ark., Listed as Melbourne, Ark.	
1889	July 19	19:32	35.2	90.0	6 - 7		Memphis, Tenn.	Local
1891	Sept. 26	22:55			5		Cairo, Ill.	
1895	Oct. 30	8:30					Corning, Ark.	Local, Three shocks
1895	Oct. 31	5:08	37.0	89.4	8 - 9		Charleston, Mo.	Felt, 1,000,000
1897	April 25	23:00			5 - 6		Osceola, Ark.	Felt, 1,000
1898	June 14				3		Corning & Osceola, Ark.	30,000
1903	Nov. 4	12:15	38.5	90.3	6 - 7		Two shocks, Belleville, Ill.	70,000
1905	Aug. 21	23:05			6		Southeast, Mo.	40,000
1909	Sept. 27	3:45	39.0	87.7	7		Palestine, Ill., listed as Indiana	30,000
1909	Oct. 23	1:10	37.0	89.5	5		Sikeston, Mo.	40,000
1911	March 31	10:57	33.8	92.2	5		Two shocks, Rison & Warren, Ark.	18,000
1915	Dec. 7	12:40	36.7	89.1	5 - 6		Arlington, Tenn.	60,000
1917	April 19	14:52	38.1	90.6	6		Between Festus & St. Genevieve, Mo.	200,000
1918	Oct. 4	3:21	34.7	92.3	5		Little Rock, Ark.	30,000
1918	Oct. 13	5:(?)			5		Black Rock or Hoxie, Ark.	9,000
1918	Oct. 15	21:30	35.2	89.2	5		Near Memphis, Tenn.	20,000
1919	April 8	6:30					Ravenden, Ark.	Local
1919	Nov. 3	14:40	36.2	90.9	4 - 5		Pocahontas, Ark.	Local
1922	March 22	16:30	37.3	88.6	5		Two shocks, Homberg, Ill.	25,000
1923	Oct. 28	11:00	35.5	90.3	7		Tyrone, Ark.	40,000
1923	Nov. 26	17:25			4		Marked Tree, Ark.	4,000
1923	Dec. 31	21:05	35.4	90.3	5		Gilmore, Ark.	30,000
1924	Jan. 1				5		Blytheville, Ark.	70,000
1925	Jan. 27				3		Batesville, Ark.	Local
1925	July 8				4		Harrison, Ark.	4,000
1927	May 7	2:28	35.6	89.0	7		Hickman, Tenn.	130,000
1928	Nov. 10	0:20			4		Black Rock, Ark.	Local
1928	Dec. 25	21:25			4		Black Rock, Ark.	Local
1930	Jan. 26	15:00			3		Black Rock, Ark.	Local
1930	Feb. 18				2		Marked Tree, Ark.	Local
1930	Nov. 16				5		Malvern, Ark.	350
1931	Dec. 10	2:11:36			4		Blytheville, Ark.	Local
1931	Dec. 16	21:36	34.0	89.7	6 - 7		Charleston, Miss.	65,000
1932	Nov. 22	1:56:42			2		Blytheville & Paragould, Ark.	Recorded at Little Rock
1933	Dec. 9	2:53:27	35.8	90.2	6		Manila, Ark.	Recorded at Little Rock
1936	March 14	11:20	34.0	95.2	5		Idabel, Okla.	900
1937	May 16	18:50	35.9	90.4	4 - 5		Monette, Ark.	25,000
1938	April 25	17:42:18			3		Findley, Ark.	Recorded at Little Rock and Cape Girardeau, Mo., giving origin time
1938	Sept. 17	21:34:23.8*	35.5	90.3	4 - 5		Tyrone, Ark.	90,000 Recorded Weston, Mass., Fordham, N. Y., Tuscon, Ariz., & Pasadena, Calif.
1939	June 19	15:42:29*	92.6	33.1	5		El Dorado, Ark.	Local
1939	Nov. 23	9:15	38.2	90.1	5		Waltonville, Ill.	150,000
1940	Feb. 14	5:10			3		Blytheville, Ark.	
1947	Dec. 15	21:27			2		Memphis, Tenn.	
1949	Jan. 13	21:50			4 - 5		Tenn. - Ark. - Mo. corner	
1950	Sept. 16	23:48					Mississippi County, Ark.	
1951	Dec.17-18	20:02:21.5					Two shocks - New Madrid, Mo. - Marked Tree, Ark.	
1952	Feb. 20	16:35	36.4	89.5	5		Tiptonville, Tenn.	
1952	April 9	10:29:15*	35.4	97.8	7		El Reno, Okla.	140,000 4 felt aftershocks
1952	Dec. 24	22:23:24*	36.1	90.0	4		Kennett, Mo.	
1953	May 12	12:50			3		Lepanto, Ark.	
1954	Feb. 2	10:53	36.7	90.3	6		Poplar Bluff, Mo.	
1954	April 26	20:09	35.2	90.2	5		Between West Memphis & Marion, Ark.	

Table 2, continued

Year	Date	Time CST	Latitude	Longitude	Intensity	Magnitude	Location from Latitude & Longitude	Felt area sq. mi.
1955	Jan. 25	1:24	35.6	90.3	6		Lepanto, Ark.	30,000
1955	March 29	3:02:40*	36.0	89.5	6		Dyersburg, Tenn.	
1956	Jan. 28	22:44	35.6	89.6	6		Covington, Tenn.	
1956	April 2	10:03	34.2	95.4	5		Antlers, Okla.	
1956	Nov. 25	22:13	37.1	90.6	6		Greenville, Mo.	21,500
1957	March 19	10:37:38	32.0	95.0	5		Four shocks between Tyler & Lufkin, Texas	10,000
1958	Jan. 26	10:55:37	35.2	90.0	5		Memphis, Tenn.	
1958	May 14	19:25					Marked Tree, Ark.	
1959	July 20	02:15:26					Blytheville, Ark.	
1960	May 4	10:31:32			4		Pine Bluff, Ark.	
1960	May 23	19:11:19					Pine Bluff, Ark.	
1961	Jan. 10	19:40			5		Hartshorne, Okla.	
1961	April 27	01:30	35.0	95.0	5		Southeastern Oklahoma	
1961	Sept. 9	16:43:02.3*	36.4	91.3	4		Ravenden Springs, Ark.	
1962	Feb. 2	0:43:34*	36.5	89.6	6		Portageville, Mo.	35,000
1962	June 1	5:23:40.5*	35.0	90.2			SW of Memphis, Tenn.	
1962	July 23	0:05:18.4*	36.1	89.8	6		Steele, Mo.	
1963	March 3	11:30:13.0*	36.7	90.1	6	4.5	Poplar Bluff, Mo.	
1964	April 28	15:18:40.1*	31.5	93.8	4 - 5	4.4	Texas-La. Border, Ten events between April 23 and Aug. 16. This the largest.	
1965	Oct. 20	20:04:38.4*	37.8	91.1	6	5.2	Berryman, Mo.	
1966	Feb. 11	22:33:14.7*	35.9	90.0	4	4.3	Blytheville, Ark.	
1967	June 4	10:14:13.6*	33.6	90.9	6	3.8	NE of Greenville, Miss.	25,000
1968	Nov. 9	11:01:41.1*	38.0	88.5	7	5.3	S of McLeansboro, Ill.	580,000
1969	Jan. 1	17:35:36.2*	34.8	92.6	6	4.2	Ferndale, Ark.	23,000
1969	May 2	05:33:19.8*	35.2	96.3	5	4.6	Lamar, Oklahoma	13,000
1970	Nov. 16	20:13.55.1*	35.9	89.9	6	3.6	Blytheville, Ark.	
1971	April 13	8:00:50.9*	35.8	90.1			SW of Blytheville, Ark.	
1971	Oct. 1	12:49:39.4*	35.8	90.4	6		Lake City, Ark.	55,000
1972	Jan. 31	23:42:10.5*	36.4	90.8	5	4.1	Datto, Ark.	
1972	March 29	14:38:31.9*	36.2	89.8	5		Caruthersville, Mo.	
1972	May 6	20:12:08.5*	35.9	90.4	4		SW of Blytheville, Ark.	
1973	Oct. 2	21:50:14*	35.9	90.0	4	3.4	SW of Blytheville, Ark.	
1973	Oct. 9	14:15:26.8*	35.6	89.6	4	3.6	Marston, Mo.	
1974	Jan. 7	19:12:37.4*	36.2	89.4		4.1	Cloverdale, Tenn.	
1974	Feb. 15	16:35:44.7*	34.05	93.13		4.2	Gum Springs, Ark. (Arkadelphia swarm)	
1974	Feb. 15	16:49:01.8*	33.96	93.03		3.8	Hebron, Ark. (Arkadelphia swarm)	
1974	Feb. 15	16:53:02.2	33.92	93.02		2.8	Hebron, Ark. (Arkadelphia swarm)	
1974	Feb. 15	21:38:55.5*	33.95	93.09		1.6	Curtis, Ark. (Arkadelphia swarm)	
1974	Feb. 16	3:43:13.7*	33.95	93.09		1.8	Curtis, Ark. (Arkadelphia swarm)	
1974	Feb. 16	3:44:35.2*	34.00	93.13		2.3	Curtis, Ark. (Arkadelphia swarm)	
1974	Feb. 24	1:53:45.2*	35.82	90.38		3.2	Lake City, Ark.	
1974	March 4	8:24:27.8*	35.68	90.35		3.0	Rivervale, Ark.	
1974	April 3	17:05:02.5*	38.59	88.09	6	4.5	Parkersburg, Ill.	
1974	May 13	00:52:18.8*	36.71	89.39	6	4.3	East Prairie, Mo.	
1974	Dec. 12	23:03:57.1*	34.67	91.88	5	3.4	Pettus, Ark.	
1974	Dec. 13	4:13:21.9*	36.70	91.63		2.8	West Plains, Mo.	
1974	Dec. 25	7:21:35.0*	35.8	90.0			S SW of Blytheville, Ark.	
1975	Jan. 2	3:18:59.7*	34.87	90.94	2	2.9	New Salem, Ark.	
1975	Jan. 10	9:31:00.8*	38.20	91.03		3.2	Mine blast, Pea Ridge Mine Mo.	
1975	Feb. 13	13:43:37.6*	36.52	89.56	5	3.5	New Madrid, Mo.	
1975	June 13	16:40:27.2*	36.54	89.68	6	4.3	Portageville, Mo.	
1975	Aug. 20	3:14:16.6*	36.56	89.80		2.9	Doniphan, Mo.	
1975	Aug. 25	1:11:08.0*	36.05	89.84		3.0	Holland, Mo.	
1976	Jan. 16	13:42:57*	35.92	92.12	4	3.2	Calico Rock, Ark.	
1976	March 24	18:41:00.5*	35.59	90.48	6	5	Trumann, Ark.	280,000
1976	March 24	19:00:11.9*	35.61	90.48		4.5	Trumann, Ark.	
1976	May 22	1:40:46.0*	36.04	89.84	5	3.2	Steele, Mo.	
1976	Sept. 25	8:06:56.0	35.61	90.45	5	3.6	Trumann, Ark.	
1977	June 2	17:19:10.4*	34.61	94.19	6	4	Mena, Ark.	
1977	Nov. 25	22:18:17*	34.52	92.96	4	3.1	Malvern, Ark.	
1978	Aug. 30	18:31:01.7*	36.21	89.52	5	3.5	Bogota, Tenn.	
1978	Sept. 23	1:33:57*	33.73	91.90	5	3.0	10 - 20 km N of Monticello, Ark.	
1978	Sept. 23	15:56:25.1*	36.31	91.25		2.8	Ravenden Springs, Ark.	
1979	Feb. 2	23:31:09.3*	35.87	90.10		3.2	Dell, Ark.	

CHRONOLOGICAL LIST OF EARTHQUAKES (1843–1978)

In the following list there are 124 entries covering the period 1843 through 1978. These breakdown into areas as follows:

Arkansas	66	Oklahoma	6
Southern Missouri	24	North Texas	3
Western Tennessee	13	Mississippi	2
Southern Illinois	9	Western Kentucky	1

These have been selected from a catalog of 390 earthquakes which include all reported events in the states listed above plus Kansas and southern Indiana. Eastern Kentucky and Tennessee events were not included as they are related to the Appalachian belt rather than the mid–Continent belts, and southwestern Texas was not included. Northern Illinois and Indiana were also not included in the catalog. The list included all earthquakes which have been felt in Arkansas or which were instrumentally located as being in Arkansas. The majority of events listed from other states have been felt in Arkansas. The exceptions are the majority of entries from Oklahoma and Texas which are included to illustrate possible sources of felt effects in western Arkansas in the event of future larger earthquakes to the west; and a few small instrumentally determined earthquakes in southeastern Missouri. The list of felt effects had not been published after the year 1977 at the time of this writing.

Early earthquakes were, of course, identified and located on the basis of felt effects. Therefore the time given is often only approximate. The first event of record that was recorded instrumentally was that of February 29, 1920 originating near Springfield, Missouri. It was recorded by the seismograph at St. Louis, Missouri. The first Arkansas epicenter determined instrumentally was that of April 25, 1938. The stations then operating at Little Rock and Cape Girardeau, Missouri both recorded this event and allowed an epicenter determination. Later in 1938 a strong quake near Tyronza, Arkansas was detected instrumentally from Massachusetts to California. In the table, instrumentally determined epicenters are given in hours: minutes: seconds. If the time is the calculated "origin time", that is the first movement apparent at the source of the shock, it is indicated by an asterisk (*) and given in Central Standard Time. Those events given to the second but without an asterisk generally mean that the quake was registered at only one instrument, not enough to determine either the precise epicenter or the origin time. The time given is the instrument time at the recording station converted to CST.

The concepts of intensity and magnitude are discussed in the first section of this Circular. Intensity is based on felt effects and decreases away from the epicenter. Two scales have been used; the Rossi-Forel scale, and the Mercalli scale as modified in 1931. In the table intensities are given in the modified Mercalli scale. A number of the smaller earthquakes in the list have been felt, but no intensity value has been assigned in the literature. In order to identify these as having been felt they have been assigned an arbitrary value of 2. The magnitude scale, popularly known as the Richter scale, is based on instrumental measurements. It is therefore not applicable to earlier events, but magnitude determinations become more common as the density of instrument stations and the refinement of the instruments themselves has progressed.

An apparent increase in the frequence of earthquakes is noticeable in the table. This is probably far less a function of nature than it is of recording and reporting. The increase in numbers of reported events in 1974 is the result of a major change in the national organization for the identification of seismic sources and the use of computers to determine them even for small events. The Arkadelphia *swarm* in 1974 probably would not have been detected a decade earlier.

The entry of April 28, 1964 is the major event of a swarm of small earthquakes on the Texas-Louisiana border. These quakes occurred in a portion of Texas that had not had any previously reported earthquakes. The Toledo Bend Reservoir on the Sabine River was completed just prior to this time and is possibly responsible for this swarm. Similar seismic events at Lake Mead on the Colorado River have been recorded and are the result of the load of water on the surface. The shocks at Lake Mead occurred during the initial impounding of the lake and subsequently when there was a marked change in water level. They were thus related to the water load. More recently a swarm of earthquakes occurred near Oroville, California commencing six years after the completion and filling of a dam in the foothills of the Sierra Nevada Mountains. At Oroville there was no correlation between earthquakes and water level so that some other mechanism other than simple weight is necessary. It appears that the hydrostatic pressure of the water in the reservoir forces water into fractures in the underlying rock ultimately lubricating them and allowing slippage. This is the same effect which caused the Denver earthquakes which were a result of waste water injection at the Rocky Mountain Arsenal. The Texas events may be of this type. With the recent completion of a number of reservoirs in Arkansas such events are possible, but not probable, here. The character of the bedrock, its fracturing, and the strain already in the rocks will determine whether such events will occur.

Sources of Information On Individual Earthquakes

At the present time the agency responsible for dissemination of information on individual earthquake and seismic activity throughout the world is the National Earthquake Information Service (NEIS) a project of the U. S. Geological Survey. This agency processes data daily from approximately 750 stations around the world including 63 stations in the USSR network. An additional 1500 stations supply data occasionally. Three levels of publications are available from NEIS. The *Earthquake Information Bulletin* is a nontechnical bimonthly bulletin with an annual subscription price of $3.00 a year (orders should be sent to: Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402). The Bulletin includes articles as well as earthquake data. The earthquake data is published about six months after the event.

The second publication is *United States Earthquakes* for each year. It is published jointly by NEIS and the U. S. Coast and Geodetic Survey – National Oceanographic and Atmospheric Administration (USC & GS, NOAA). It is a complete compilation of all data of felt earthquakes in the U. S. It generally has a lag time of two years: thus USEq, 1976 was published in 1978. It was begun in 1928 and compilation volumes "USEq through 1940" and "USEq through 1970" have been issued.

The technical publications of NEIS include "Preliminary Determination of Epicenters Cards" (PDE), "Preliminary Determination of Epicenters Monthly", and "Earthquake Data Reports." These give instrumental data on approximately 6,000 earthquakes a year. The PDE Cards are the first notice to instrument stations on the location of earthquake centers. Approximately 40 are issued each year with events taken up by priority. Large damaging quakes are given first priority and small unfelt events such as many in Arkansas are given low priority. As these data were important in making up the following catalog the data presented here for 1978 is probably incomplete.

1843

January 4 21:30 Memphis, Tennessee

One of the great earthquakes of the Mississippi Valley region. The epicenter has been variously placed as New Madrid or Memphis, but the latitude and longitude invariably given is that of Memphis. At Memphis the effects were destructive; chimneys fell, brick walls cracked, windows were broken and houses shook. One building reputedly collapsed. It was reported to have lasted two minutes and accompanied by a dismal rumbling. At New Madrid land sank and there were unconfirmed reports that two hunters drowned when a lake was created. At St. Louis there was general terror and one chimney fell. The shock was felt generally throughout Arkansas with three separate shocks reported at Van Buren. A shock was felt from the seacoast of Georgia and Providence, Rhode Island to beyond the frontier outposts of the west. This implies a felt area almost as great as the 1811-1812 shocks.

Reference: Branner, Heinrick, Heck, and USEq through 1970

1865

August 17 9:00 Southeast Missouri

A severe earthquake felt generally in southern Illinois, western Tennessee, northwestern Mississippi, northeastern Arkansas, as well as southeastern Missouri. The given latitude and longitude places the epicenter south of New Madrid. There objects fell from shelves, chimneys were damaged, and animals alarmed. Waves were created on the river like a passing steamboat and the earth seemed to roll in waves in a swampy area. At St. Louis dishes rattled and bells were rung, furniture rocked, and there was a cracking sound in houses. At Memphis it was strong, chimneys fell and loose articles were upset.

Reference: Branner, Heinrich, Heck and USEq through 1970

1878

November 18 11:52 Southeast Missouri

The latitude and longitude given places it near Poplar Bluff, Missouri. Felt over an elliptical area extending from Leavenworth, Kansas to Tuscaloosa, Alabama and from Clarksville, Arkansas to a point midway between Cairo, Illinois and St. Louis; an area 600 by 300 miles. At Cairo trembling lasted forty seconds, strong frame buildings vibrated and creaked at every joint. Severe along the Missouri River from Glasgow to Lexington. Felt at Little Rock.

Reference: Branner, Heinrich, Merriam, Heck, and USEq through 1970

1879

September 25 21:00 Memphis, Tennessee

"A slight shock of an earthquake was felt . . ." at Memphis. "The vibrations were very perceptible." Also felt at Gayoso, Missouri.

Reference: Heinrich

1880

July 13 20:25 Memphis, Tennessee

A shock felt at Memphis and Gayoso, Missouri at 8:25 PM and a second tremor at 8:40 PM.

Reference: Heinrich

1882

October 22 Arkansas

The latitude and longitude given places it between Waldron and Booneville. The shock was felt in north Texas, Oklahoma, west Arkansas, and east Kansas; from Paris, Texas to Wichita and Leavenworth, Kansas. Houses were shaken at Fort Smith and it was distinctly felt at Boonsboro (Cane Hill). At Sherman, Texas heavy machinery vibrated, and bricks were thrown from chimneys. It was difficult to get an accurate origin point due to insufficient reports from the area most affected.

Reference: Branner, Heinrich, Heck, Merriam, and USEq through 1970

1883

January 11 01:12 Cairo, Illinois

A strong shock from St. Louis to Memphis. Four distinct shocks felt at St. Louis described as a swaying motion. Buildings rocked, chandeliers swung, and engine bells rang. The greatest motion was at Cairo.

Reference: Branner, Heinrich, Heck, and USEq through 1970

April 12 02:30 Cairo, Illinois

A strong shock characterized by short jerky vibrations rattled windows and shutters awakening everyone. One old frame house was reported shaken down, resulting in slight injury to inhabitants. Duration estimated at thirty seconds.

Reference: Branner, Heinrich, Heck, and USEq through 1970

June 11 12:16 Memphis, Tennessee

Three shocks reported at Memphis, 12:16, 12:30, and 13:13. The third shock was the heaviest and accompanied by rumbling. Buildings were shaken and people rushed out. Heinrich presents evidence that this event may be misdated.

Reference: Branner, Heinrich

December 5 09:20 Arkansas

The location of the center is confused; Branner places it in Boone County; most lists say Izard County, but the latitude and longitude in most lists is in Fulton County. The maximum felt effect was near Melbourne in Izard County. It is also listed as centered at Ravenden Springs, Missouri instead of Arkansas. At Ravenden Springs glassware and crockery were broken. Rocks were loosened and fell in cuts of the Kansas City-Springfield-Memphis Railroad. At Melbourne buildings were shaken accompanied by a thunder-like rumbling.

Reference: Branner, Heinrich, Heck, and USEq through 1970

1884

November 29 West Tennessee

Vibrations and rumbling distinctly felt and heard for about five seconds at Dyersburg and Covington, Tennessee. The vibrations seemed to travel from the southwest to the northeast.

Reference: Heinrich

1886

August 31 21:51 Charleston, South Carolina

The great Charleston earthquake was felt as far west as the Mississippi River Valley. At Augusta, Arkansas two shocks were felt; the first of five second's duration. There was no sound and the motion was undulatory. At DeValls Bluff there was one very distinct shock and two or three light tremors. At Helena two or three shocks at one minute intervals were felt. At Jonesboro one very light shock was felt by a few people on second floors but was not felt on the ground floors. At Sans Souci there were two shocks. On a steamer tied to the Mississippi River bank the ship lurched sidewise at the first shock. The earthquake was not felt at Little Rock, Osceola, Monticello, Hampton, or Pocahontas. The distinctly felt shocks were all from locations on rivers.

Reference: Dutton

1887

August 2 12:36 Cairo, Illinois

A severe shock widely felt in Missouri, Kentucky, Tennessee, and Illinois. Stopped clocks and frightened people.

Reference: Heinrich, USEq through 1970

1889

July 19 17:32 Memphis, Tennessee

A shock strong enough to swing hanging articles to and fro. Walls and ceilings cracked, people frightened.

Reference: Branner, Heinrich, USEq through 1970

1891

September 26 22:55 Cairo, Illinois

An earthquake which began slowly and gained strength in a few seconds. Moveable objects jiggled and trees swayed as if by wind. Felt in several localities in Iowa.

Reference: Heinrich, Heck, and USEq through 1970

1892

January 14 03:05 Memphis, Tennessee

Shook houses. This is one of a number of minor earthquakes in Memphis which are listed by Heinrich as a result of a search of the Memphis Weather Bureau records by Letsinger in 1938. They are not otherwise reported.

Reference: Heinrich

1895

October 30 08:30 Corning, Arkansas

Light tremors at 08:30, 14:00, and 16:30. Entered in the list as one event.

Reference: Heinrich

October 31 05:08 Charleston, Missouri

A shock felt over a 23 state area, considered the hardest shock since 1811-12. The maximum damage was at Charleston, Missouri where every building in the commercial area was damaged. Four acres of ground sank creating a lake and numerous extrusions of sand and water occurred. The shock was felt from Canada to Louisiana and from the Carolinas to New Mexico and Nebraska. Foreshocks were felt on October 18 and 30 and after shocks were felt on November 1 (20:16), 2 (2:00 and 11:00), and 17. At Fort Smith the shock was felt by a few. At Little Rock it was generally felt and estimated one minute's duration. It was also reported felt at Brinkley, Forrest City, LaCrosse, Osceola, Pocahontas, Helena, and Corning. There was apparently no damage in Arkansas.

Reference: Branner, Heinrich, Merriam Heck, and USEq through 1970

1897

April 25 22:00 Osceola, Arkansas

Shock at Osceola, Arkansas. In Cairo, Illinois large buildings swayed and people rushed to the streets in terror.

Reference: Branner, Heinrich

April 30 22:00 Mississippi Valley

A shock was felt in Tennessee, Illinois, and other states in the Mississippi Valley. Duration variously estimated from 2 to 20 seconds.

Reference: Heinrich

1898

June 14 09:20 Corning and Osceola, Arkansas

Generally felt throughout the New Madrid area, strongest at Corning and Osceola. It was reported felt at New Madrid and at points in Kentucky, Indiana, and Tennessee.

Reference: Branner, Heinrich

1903

November 4 12:15 and 13:18 Belleville, Illinois

Two shocks which were felt in eight states in the central Mississippi Valley. The latitude and longitude given is Belleville, Illinois but it is generally listed as at St. Louis, Missouri. At New Madrid and Cape Girardeau, Missouri and at Cairo, Illinois there was damage including cracked walls and fallen chimneys. Foreshocks were felt on October 4 and aftershocks were felt on November 24 and 27.

Reference: Branner, Heck, Heinrich and USEq through 1970

1905

August 21 23:08 Memphis, Tennessee

The latitude and longitude given are those for Memphis although it is listed as Mississippi Valley and southeast Missouri. Reported felt in Missouri, Illinois, Mississippi, Indiana, Kentucky, and Tennessee, therefore presumably felt in northeast Arkansas. The most severe effects were at Sikeston, Missouri where several buildings cracked and chimneys fell. In St. Louis it was assigned a maximum intensity of VI and several reports say "old roof collapsed"; however, other reports place the collapse the next day as a result of strong winds on the damaged roof of the Education Building of the St. Louis World's Fair.

Reference: Branner, Heck, Heinrich, USEq through 1970

1909

September 27 3:45 and 3:50 Palestine, Illinois

Generally listed as Indiana. Felt in the southwest half of Indiana, all of Illinois, eastern Iowa and Missouri, the west half of Kentucky, and northern Arkansas. Chimneys fell, buildings cracked, light connections severed, and pictures shaken from the walls at Vincennes and Terre Haute, Indiana.

Reference: Heck, USEq through 1970

October 23 1:10 Sikeston, Missouri

Listed as southeast Missouri. Felt from St. Louis to the northwest corner of Mississippi, 300 miles by 200 miles east-west. The area affected including Missouri, Arkansas, Mississippi, Tennessee, Kentucky, Indiana, and Illinois. This was the first local earthquake recorded by the seismographs at St. Louis University. At Cape Girardeau, Missouri the shock was so severe that some fled from their homes.

Reference: Heinrich, USEq through 1970

1911

March 31 10:57 and 12:10 Rison, Arkansas

Two shocks variously listed as Rison, Warren, and Pine Bluff, Arkansas. At Pine "the shocks were so severe that . . . hundreds of excited residents crowded the streets in panic . . . windows were broken in various parts of the city. At Sixth Avenue School the walls of the building were cracked and plastering fell on the pupils . . . glasses were shaken from counters of confectionery stores and dishes were broken in many kitchens." At Rison houses swayed and articles were thrown from shelves. The shock was felt throughout southeast Arkansas, northeast Louisiana, and along the Mississippi River from Memphis to Vicksburg.

Reference: Branner, Heck, Heinrich, and USEq through 1970

1915

December 7 12:40 Arlington, Kentucky

A sharp earthquake centered near the mouth of the Ohio River, generally listed as at Cairo but latitude and longitude is close to Arlington. The position was determined by instrumental records by H. F. Reid. Felt on both sides of the Mississippi River for a distance of 200 miles. The shock caused houses to shake and frightened people at Cairo, Illinois.

Reference: Heinrich, USEq through 1970

1917

April 9 14:52 St. Genevieve, Missouri

A strong shock from St. Louis to New Madrid, Missouri. At St. Genevieve and St. Mary's people ran into the streets, buildings rocked and windows rattled, many breaking. A rumbling sound accompanied the shock. At St. Louis large buildings rocked and people were reported thrown from their feet. In Arkansas various effects were reported. At Black Rock windows trembled; at Corning there was a rumbling sound and buildings shook; at Marked Tree furniture moved. The shock was estimated to have lasted 30 to 60 seconds. A second shock was felt at 17:38 in southern Missouri. The main shock was felt from Kansas to Ohio and from Wisconsin to Mississippi.

Reference: Heck, Merriam, Heinrich, and USEq through 1970

1918

October 4 3:21 Little Rock, Arkansas

Abrupt tremors felt at Little Rock, Memphis, and Black Rock, Arkansas. Center placed 20 to 30 miles southeast of Little Rock. Branner lists this event as at Black Rock.

Reference: Branner, Heck, Heinrich, and USEq through 1970

October 13 3:30 Black Rock, Arkansas

A shock of 30 seconds duration. Branner places this event at Hoxie, Arkansas. Coffman and von Hake indicate three abrupt shocks with intensity V at Hoxie and Pocahontas.

Reference: Branner, Heinrich, and USEq through 1970

October 15 21:30 Western Tennessee

The latitude and longtitude given places the center just east of Memphis. Felt from Cairo and Anna, Illinois, throughout western Kentucky and Tennessee, and at Black Rock and Hardy, Arkansas. The motion was described as rocking and trembling with an estimated duration of 1 - 5 seconds. The time of the event is variously reported from 8:15 to 8:30 and 9:30 PM.

Reference: Heinrich, Heck, and USEq through 1970

1919

April 8 6:30 Ravenden, Arkansas

The Monthly Weather Review (1919 p. 271) reports this event and states that "the disturbance was possibly not of seismic origin." No details are available.

Reference: Heinrich

November 3 14:40 Pocahontas, Arkansas

Trembling and loud rumbling generally felt in the vicinity of Pocahontas.

Reference: Branner, Heck, Heinrich, and USEq through 1970

1922

March 22 16:30 and 20:20 Homberg, Illinois

Two shocks felt in parts of five states from Arkansas to Indiana. There was only slight damage consisting mainly of falling chimneys and plaster. The tremors rattled chinaware and dislodged pictures.

Reference: Heck, Heinrich, and USEq through 1970

March 30 10:53 Memphis, Tennessee

A distinct tremor continuing for 3 or 4 seconds. Windows were rattled and pictures and mirrors were shaken from walls in Memphis. The shock was reported felt in south Illinois, Kentucky, and southeast Missouri.

Reference: Heinrich

1923

October 28 11:00 Tyronza and Marked Tree, Arkansas

Felt in Arkansas, Kentucky, Missouri, Mississippi and Tennessee. Windows were shattered, several old chimneys fell, and walls were cracked. The surface of the St. Francis River was affected at Marked Tree.

Reference: Branner, Heck, Heinrick, and USEq through 1970

November 26 17:25 Marked Tree, Arkansas

Shock felt in Arkansas and Tennessee and the southern part of the New Madrid area.

Reference: Branner, Heinrich

December 31 21:05 Gillmore, Arkansas

Latitude and longitude given place it here although most reports give maximum intensity just west of Memphis. Felt in Arkansas, Tennessee, Kentucky, Illinois, Missouri, and Alabama.

Reference: Branner, Heck, Heinrich, and USEq through 1970

1924

January 1 Blytheville, Arkansas

Maximum felt distance 150 miles, felt over a larger area than the event the day before but listed only by Branner.

Reference: Branner

January 27 Batesville, Arkansas

A local event not reported outside of the immediate area.

Reference: Branner

1925

July 8 Harrison, Arkansas

The only event reported in the northwest quarter of the state. Maximum felt distance 35 miles.

Reference: Branner

1927

May 7 2:28 Hickman, Tennessee

The latitude and longitude given indicates a Tennessee source although the maximum felt effect was in north Jonesboro, Arkansas. There some chimneys were tumbled down and buildings rocked. Felt from Pocahontas, Arkansas to Carbondale, Illinois and Decatur, Alabama. The time given varies but it was recorded instrumentally in St. Louis at 2:31 which would make 2:30 a closer time.

Reference: Branner, Heck, Heinrich, and USEq through 1970

1928

November 10 00:20 Black Rock, Arkansas

Shock appeared to come from the west.

Reference: Branner, Heinrich

December 25 21:25 Black Rock, Arkansas

Trembling causing windows to rattle.

Reference: Branner, Heinrich

1930

January 26 15:00 Black Rock, Arkansas

A slight shock felt by many locally.

Reference: Branner, Heinrich

February 18 11:00 Marked Tree, Arkansas

A feeble shock accompanied by subterranean sounds.

Reference: Branner

March 27 2:56 Memphis, Tennessee

Reference: Heinrich

November 16 Malvern, Arkansas

Local shock with maximum felt distance of 10 miles.

Reference: Branner

1931

December 10 2:11 Blytheville, Arkansas

A shock felt from Wilson, Arkansas to Hayti, Missouri rattled windows in Blytheville. Instrumental origin time 2:11:36.

Reference: Branner, Heinrich

December 16 21:36 Charleston, Mississippi

At Charleston there were cracks in walls and foundations, some chimneys were thrown down. Damage also occurred at Belzoni, Tillatoba, and Water Valley, Mississippi. Felt in Alabama, Arkansas, and Tennessee.

Reference: Heinrich and USEq through 1970

1932

November 22 1:57 Blytheville and Paragould, Arkansas

A slight shock felt at these cities and recorded instrumentally at Little Rock.

Reference: Heinrich

1933

December 9 2:40 Manila, Arkansas

Windows broken at Manila by two distinct shocks. Tables list the time as 2:40 but a shock was recorded instrumentally at Little Rock at 2:53:27. This is too late for a 2:40 origin time and may represent the second shock.

Reference: Heck, Heinrich, and USEq through 1970

1936

March 14 11:20 Southeast Oklahoma

The latitude and longitude given places the source between Idabel and Hugo. Event indicated felt only at Valliant and Wright City. The sources of events in this area of the state are frequently very vague in the literature.

Reference: Heck, Heinrich, and USEq through 1970

1937

May 16 18:50 Monette, Arkansas

Not strong but felt over a large area of northeast Arkansas and adjacent parts of Missouri, Tennessee, and Kentucky. At Corning it shook and rattled dishes but did no damage. Felt at Batesville and Lepanto.

Reference: Heck, Heinrich, Robertson, and USEq through 1970

1938

April 25 17:42 Findley, Arkansas

A slight tremor felt and recorded instrumentally at Little Rock and Cape Girardeau. Origin time 17:42:18.

Reference: Heinrich

September 17 21:34 Tyronza, Arkansas

Felt over most of Arkansas and much of Tennessee, Mississippi and Missouri and parts of Kentucky, Illinois, and Oklahoma. The event was recorded instrumentally from Massachusetts to California resulting in accurate location of the epicenter and determination of origin time. This is the first local earthquake reported as recorded over such a wide area. The belt of maximum felt effects extended west of the Mississippi from Blytheville through Forrest City to the mouth of the Arkansas River and included Greenville and Cleveland, Mississippi. It was felt as far west as Hot Springs and north to Cape Girardeau, Missouri. Further to the west there were local areas of minor felt effects around Fort Smith, Muskogee, Oklahoma, and in the Fayetteville to Harrison areas.

Reference: Heck, Heinrich, Walter, and USEq through 1970

1939

June 19 15:43 South of El Dorado

An earthquake felt throughout southern Arkansas. Cracked plaster in some buildings in Arkadelphia. Reported felt at Crossett, Dumas, Fordyce, Hot Springs, Pine Bluff, and Prescott as well as El Dorado and Arkadelphia. Epicenter and origin time determined instrumentally.

Reference: Heck, Heinrich, and USEq through 1970

November 23 Waltonville, Illinois

An earthquake just short of destructive intensity at Griggs, Illinois with the instrumentally determined epicenter at Waltonville. Felt over most of Illinois and Missouri and parts of Wisconsin, Indiana, Kentucky, Mississippi, Arkansas, and Iowa.

Reference: Heinrich and USEq through 1970

1940

February 14 5:10 Blytheville, Arkansas

A slight shock of about thirty seconds duration reported only from Blytheville.

Reference: Heinrich

1941

June 28 12:30 Vicksburg, Mississippi

Slight shock, no details given.

Reference: USEq, 1941

October 8 1:51 Blytheville, Arkansas

Slight damage reported at Blytheville and Tiptonville, Tennessee. No details given.

Reference: USEq, 1941

November 14 21:07 Memphis, Tennessee

Shock felt by many.

Reference: USEq, 1941

November 16 21:09 Covington, Tennessee

At Covington the shocks were felt by all and cracks were reported in the courthouse. At Henning, Tennessee the shocks were preceeded by an explosive noise and trembling. Felt from Memphis to Dyersburg, Tennessee.

Reference: USEq, 1941

1946

May 15 00:10 Marston and Doniphan, Missouri

Slight to rather intense local shock, no details available.

Reference: USEq, 1946

1947

December 1 2:47 Poplar Bluff, Missouri

Felt at Poplar Bluff and New Madrid. A light shock arounsed many residents. The State Highway Patrol reported a rumbling sound several seconds before the "explosion" which "sounded like a truck ran into the side of a building."

Reference: USEq, 1947

December 15 21:27 Memphis, Tennessee

Slight shock felt in an area extending from Lepanto, Arkansas to Brownsville, Tennessee and Hernando, Mississippi. No felt reports were received from the area west of Memphis.

Reference: USEq, 1947

1949

January 13 21:50 Tennessee - Arkansas - Missouri corner

Houses shook and dishes rattled in western Tennessee, eastern Arkansas, and southern Missouri. Felt from Cairo, Illinois to Memphis, Tennessee. Wayne, Blytheville, Luxora, and Osceola, Arkansas all reported a slight tremor. At Tipton, Tennessee residents reported one hard shock followed by three pulsating rolling waves of one second duration each.

Reference: USEq, 1949

1950

September 16 23:48 Mississippi County, Arkansas

Felt at Driver, Edmonson, Luxora, Osceola, Riverdale, and Roseland, Arkansas and in Tennessee south to Memphis. Recorded in St. Louis.

Reference: USEq, 1950

1951

December 17 20:02 New Madrid, Missouri

A light shock felt in the vicinity of New Madrid and at Marked Tree and Lepanto, Arkansas. A second weak shock was felt on December 18 at 02:00.

Reference: USEq, 1951

1952

February 20 16:35 Tiptonville, Tennessee

Felt by many in the corner area of Tennessee, Kentucky, Missouri and Arkansas.

At Tiptonville some merchandise toppled from a store shelf and many people rushed to the streets. Store displays toppled and bottles thrown from shelves in Hickman, Kentucky. Felt throughout the bootheel of Missouri and in Clay, County, Arkansas.

Reference: USEq, 1952 and USEq through 1970

April 9 10:29 El Reno, Oklahoma

Felt from Austin, Texas to north of Des Moines, Iowa and from the easternmost portion of the panhandle of Texas to Little Rock. Intensity VII in El Reno, Oklahoma City, and Ponca City where it was felt by all and some near panic. A few chimneys fell and walls were cracked. Plate glass windows were broken, dishes broke, books and canned goods tumbled from shelves. Walls were cracked at various places throughout central Oklahoma. At Tulsa office workers in taller buildings were terrified, walls cracked and cracked plumbing was reported. In Arkansas the earthquake was felt strongly at Fort Smith without damage. It was also felt at Clarksdale, Clarksville, Dardanelle, Fayetteville, Harrison, Little Rock, Magnolia, and Texarkana. Felt aftershocks were reported April 11 14:30, April 16 00:05, July 16 18:30 and 20:00, and August 14 15:40.

This is the only event from this region which was felt in Arkansas but there have been a number of events from this area. On September 10 & 11, 1918, there was a series of small felt events. On December 27, 1929 there was an earthquake which reached Intensity VI and a similar event on August 19, 1933 both at El Reno. March 17, 1953 a small event was felt at Concho, Union City, and El Reno. The most recent was on December 16, 1970 which was determined instrumentally as centered at Norman. Future events from this region may well be felt in Arkansas.

Reference: USEq, 1952 and USEq through 1970

December 24 22:23 Blytheville, Arkansas

The instrumental epicenter places this event near Kennett, Missouri but the maximum felt effects were at Blytheville. A sharp tremor of five seconds duration accompanied by a distant rumble. Houses shook and Christmas trees swayed. Also felt at Jonesboro, southeast Missouri and Memphis, Tennessee.

Reference: USEq, 1952

1953

May 12 12:50 Lepanto, Arkansas

Felt by several as one quick jolt lasting less than a second. One report of a floor shaking.

Reference: USEq, 1953

1954

February 2 10:53 Missouri-Arkansas border

Listed also as Pocahontas, Arkansas - Poplar Bluff, Missouri. The latitude and longitude given places the center east of Poplar Bluff. The shock caused slight damage at Poplar Bluff where plaster fell from a ceiling and at Pocahontas where a wall was cracked in a school building. It was also felt in parts of Illinois and Tennessee. In Arkansas it was felt without damage at Biggers, Dalton, Datto, Engelberg, Maynard, Middlebrook, Pitman, and Success.

Reference: USEq, 1954 and USEq through 1970

April 26 20:09 Memphis, Tennessee

Latitude and longitude given places this event in Arkansas between West Memphis and Marion. Felt from Blytheville, Arkansas and Jackson, Tennessee to Corinth, Mississippi.

Plaster cracked and houses trembled at Memphis, Tennessee.

This is the first local earthquake recorded at Fayetteville since the station was established in 1952. From this event onward in this list Fayetteville data will be given where available in date, time GCT, S–P interval, and maximum trace amplitude on the records.

Fayetteville: 4/27 02:09:52 S–P 52 sec. Amp. 90 mm.

Reference: USEq through 1970

1955

January 25 01:24 Tennessee-Arkansas-Missouri border

Latitude and longitude given from instrumental data are for Lepanto, Arkansas. Felt from Lepanto northward to Paducah, Kentucky and eastward to Birmingham, Alabama. The maximum felt effects were at Dyersburg and Finley, Tennessee where furniture shifted several inches, houses cracked, and canned goods were shaken from the shelves. Rumbling or roaring noises were reported in several localities in western Tennessee. At Hayti, Missouri windows were cracked. In Arkansas it was widely felt in the northeast corner as far west as Randolph County and as far south as Crittenden County.

Fayetteville: 1/25 07:25:34 S–P 48 sec. Amp. 40 mm.

Reference: USEq, 1955 and USEq through 1970

March 29 03:03 Finley, Tennessee

A roaring noise and violent shaking. Plaster cracked in one house. Felt in Dell, Arkansas.

Fayetteville: 3/29 09:02:50 S–P 50 sec. Amp. 2 mm.

Reference: USEq, 1955 and USEq through 1970

1956

January 28 22:44 Arkansas-Tennessee Border

Latitude and longitude given locates this at Covington, Tennessee where the maximum felt effects were reported. There chimneys and walls were cracked. At Armorel, Arkansas the shock was flet by nearly all and many were awakened. Houses shook and the shock was accompanied by a rumbling noise like thunder. Blytheville, Hurlbert and Osceola reported the event at Intensity IV and was felt at lesser intensities at Driver, Lepanto, Luxora, Tomato, Victoria, West Memphis, and Wilson, Arkansas. Felt extensively in western Tennessee.

Fayetteville: 1/29 04:45:13 S–P 57.5 sec. Amp. 60 mm.

Reference: USEq, 1956 and USEq through 1970

April 2 10:30 Southeastern Oklahoma

Felt by and alarmed many at Antlers, Oklahoma. Buildings shook and objects fell from kitchen walls. Windows and loose objects rattled. The shock was accompanied by thunderous, rattling, and bumping noises heard by many. Also felt at Broken Bow, Idabel, Hugo, Sawyer, Sobel, and Valliant, Oklahoma. Not reported felt in Arkansas.

Location of sources of seismic events in this area of Oklahoma is difficult since there are instrument stations close enough to pick up small earthquakes.

Fayetteville: 4/2 16:03:18 S–P 27 sec.

Reference: USEq, 1956 and USEq through 1970

November 25 22:13 Wayne County, Missouri

Latitude and longitude given places this earthquake north of Greenville, Missouri on the instrumental data. Felt area included parts of Arkansas, Illinois, Kentucky, Missouri, and Tennessee. Windows were shattered and walls cracked at Grubville, Richmond Heights, St. Louis, and Sturdivant, Missouri. Felt in Arkansas at Pocahontas, Beech Grove, Dell, Nimmons, Success, and Twist.

Fayetteville: 11/26 04:13:34 S–P 49 sec. Amp. 23 mm.

Reference: USEq, 1956 and USEq through 1970

1957

March 19 16:36 and 16:45 Northeast Texas

Latitude and longitude given places this between Tyler and Lufkin, Texas. Felt over northeast Texas and adjacent Louisiana and Arkansas. A few objects upset and a few windows broken in Texas. Felt at Magnolia, Canfield and Stamps, Arkansas. At and near Magnolia a few objects were shaken from tables and stoves.

Fayetteville: not recorded, good record

Reference: USEq, 1957 and USEq through 1970

1958

January 26 10:55 Memphis, Tennessee

Felt by many and some alarmed. Kitchen utensils and clock fell, dishes and houses rattled, and floors shook at Memphis. Minor damage at Caruthersville, New Madrid, and Sikeston, Missouri. Not reported but probably throughout eastern Arkansas.

Fayetteville: 1/26 16:53:33 S–P 51.6 sec. Amp. 18.5 mm.

Reference: USEq, 1958 and USEq through 1970

May 19 19:25 Marked Tree, Arkansas

Felt only locally. Reported to Fayetteville Station.

Fayetteville: Not recorded, good record.

Reference: Not listed in literature

1959

July 20 02:15 Blytheville, Arkansas

Felt by several with an abrupt onset and a bumping motion.

Fayetteville: 7/20 08:15:35 S–P 33 sec. Amp. 17 mm.

Reference: USEq, 1959

1960

May 4 10:21 Pine Bluff, Arkansas

Felt by many, houses shook and bottles on shelves rattled. Near Pine Bluff a building vibrated for two seconds.

Fayetteville: 5/4 16:32:26 S–P 33 sec. Amp. 45 mm.

Reference: USEq, 1960

May 23 23:19 Pine Bluff, Arkansas

Reported felt to Fayetteville Seismograph Station. Not listed in the literature.

Fayetteville: 5/24 01:11:09 S–P 39.5 sec. Amp. 26 mm.

Reference: Fayetteville Seismograph Bulletin Vol. 9

1961

January 10 19:40 Southeastern Oklahoma

At Dow and Hartshorne, Oklahoma buildings creaked; doors, windows and loose objects rattled; and hanging objects swayed. A rolling to trembling motion with an abrupt onset accompanied by a thunderous sound. Reported felt as far east as Poteau and Heavener.

Fayetteville: Not recorded.

Reference: USEq, 1961

April 27 01:30 Southeastern Oklahoma

Felt with Intensity V from Antlers and Coalgate in the southwest to Poteau and McCurtain at the northeast end of the belt. Buildings shook and windows, doors and dishes rattled. A bumping and trembling motion with an abrupt onset accompanied by thunderous and deep rumbling soungs. Felt less strongly from Vian to Idabel. Probably felt in Arkansas but not reported.

Fayetteville: Not recorded.

Reference: USEq, 1961

September 9 16:43 Arkansas-Missouri Border

Latitude and longitude given places the center northwest of Ravenden Springs, Arkansas. At Doniphan, Missouri buildings shook and loose objects rattled. The motion had a rapid onset and sounded like a sonic boom. At Pocahontas, Arkansas doors rattled from a bumping motion with an abrupt onset.

Fayetteville: 9/9 22:43:46 S–P 49 sec. Amp. 4.5 mm.

Reference: USEq, 1961

1962

February 2 00:43 New Madrid, Missouri

Instrumental latitude and longitude place epicenter at Portageville, Missouri. Maximum felt effects were at Catron and Marston, Missouri where a few walls and plaster cracked, a chimney fell, and windows cracked. Buildings creaked, rattled and shook, a few objects fell, and hanging objects swayed. In northeast Arkansas the maximum felt effects were at Jonesboro, Maynard, Osceola, and Tulot where windows and dishes rattled. Sounds were heard ranging from a continuous roar to distant rumbling. Felt in Arkansas, Illinois, Kentucky, Missouri, and Tennessee.

Fayetteville: 2/2 06:44:30 S–P 56.8 Amp. 80 mm.

Reference: USEq, 1962 and USEq through 1970, Street et. al., Focal Mechanism, No. 1.

June 1 5:23 Memphis, Tennessee

Not reported as felt.

Fayetteville: Station not operating.

Reference: Street et. al., Focal Mechanism No. 2.

July 23 00:05 Southern Missouri

Instrumental latitude and longitude places the epicenter at Steele, Missouri. Maximum felt effects were at Dyersburg, Tennessee where building shook; windows, doors, dishes, and kitchen utensils rattled; and beds jumped. A rapid onset with rolling or bumping motion reported in Tennessee and several towns reported that it "felt like a heavy object hitting the building". Thunderous sounds reported. The only Arkansas felt reports were from Osceola.

Fayetteville: 7/23 06:06:14.5 S–P 60 sec. Amp. 2 mm.

Reference: USEq, 1962 and USEq through 1970, Street et. al., Focal Mechanism No. 4

1963

March 3 11:30 Southeast Missouri

Instrumental latitude and longitude places the epicenter east of Poplar Bluff, Missouri. Maximum felt effects in Missouri east of Poplar Bluff and into the northern bootheel. Bricks fell from chimneys, plaster and walls cracked; foundations, sidewalks, chimneys and windows cracked at various towns. Water lines were broken and basements flooded at Poplar Bluff. Felt in Arkansas, Illinois, Indiana, Kansas, Kentucky, Mississippi, Oklahoma, and Tennessee. In Arkansas there was slight damage at Carryville, Corning, Edmondson, Lafe, Piggott, and State College; mostly cracked plaster, walls and windows. At Edmondson a storage bin with approximately 60,000 pounds of seed slipped off blocks and fell. Earth noises heard widely mostly described as roaring or rumbling.

Fayetteville: 3/3 17:34:04 S–P 50 sec. Amp. 110 mm.

Reference: USEq, 1963 and USEq through 1970, Street et. al., Focal Mechanism No. 5.

1964

April 28 15:18 Texas-Louisiana Border

A series of earthquakes of which this was the strongest. Plaster cracked at Hemphill, Texas on April 28 and August 16. This is an area from which earthquakes had not previously been reported. Toledo Bend Reservoir on the Sabine River had been completed and filled and these earthquakes may be the result of that.

Individual events were reported on:

April 23	19:20:55	mag. 3.7
April 24	01:33:53	mag. 3.7
April 27	18:30:45.6	mag. 3.4
April 28	15:18:40	mag. 4.4
April 30	14:30	
May 7	14:10	
June 2	17:00	
June 2	19:30	
June 2	20:27:24	mag. 4.2
Aug. 16	05:36	

Fayetteville:

4/24	01:22:04.7	Amp. 9 mm.
4/24	07:35:00.9	S–P 80 sec. Amp. 20 mm.
4/27	00:31:55.4	S–P 55 sec. Amp. 11 mm.
4/28	21:18:30	
6/ 3	02:28:35.5	Amp. 3.5 mm.

Reference: USEq, 1964 and USEq through 1970

1965

October 20 20:04 Eastern Missouri

Instrumental latitude and longitude places epicenter near Berryman, Missouri. Felt from Memphis, Tennessee to Des Moines, Iowa and from Emporia, Kansas to Chicago, Illinois. The maximum felt effects were along a northeast trending belt through St. Louis. Various towns reported cracked walls, plaster, and windows. Maximum felt effects in Arkansas were at Piggott and Rector where buildings creaked, loose objects rattled, and chairs and beds shook.

Fayetteville: 10/12 record missing, not recorded in Bulletin

Reference: USEq, 1965 and USEq through 1970, Street et. al., Focal Mechanism No. 15.

1966

February 11   22:23   Eastern Arkansas

Instrumental latitude and longitude places epicenter southwest of Blytheville. Creaking of buildings was reported in Blytheville, Delbridge, Leachville, Manila and Steele.

Fayetteville 2/12 04:33:08.5 Amp. 2.5 mm.
Reference: USEq, 1966, Street et. al., Focal Mechanism No. 17

1967

June 4   10:14   near Greenville, Mississippi

Epicenter near Meltonia 18 miles northeast of Greenville. The felt area extended from Memphis, Tennessee to Attica, Mississippi and from Rison, Arkansas to Kosciusko, Mississippi. A few cases of cracked plaster were reported and one earth crack ¼ to ½ inch wide and 39 feet long was reported near the epicenter. The maximum felt effects in Arkansas were noted at Halley, Helena, and McGehee.

Fayetteville: Not reported.

Reference: USEq, 1967 and USEq through 1970, Street et. al., Focal Mechanism No. 21.

1968

January 4   16:30   Hartshorne, Oklahoma

A local earthquake felt by several at Hartshorne with rattling of doors and windows. Felt from Haileyville to Gowan, a distance of 10 miles.

Fayetteville: Not operating.

Reference: USEq, 1968

November 9   11:02   South-central Illinois

Instrumental epicenter south of McLeansboro, Illinois. Felt over all or parts of 23 states from western Pennsylvania to northeast Oklahoma and from southeast Minnesota to central Georgia and western Carolinas. It was the strongest shock in this region since 1895. Minor damage extended from Evansville, Indiana, Henderson, Kentucky, St. Louis, Missouri to Chicago, Illinois. It was reported felt in tall buildings as far away as Toronto, Ontario, Boston, Massachusetts, and Mobile, Alabama. Damage consisted chiefly of bricks thrown from chimneys, broken windows, toppled TV antennas, and cracked plaster. In the epicentral area chimneys were downed, foundations cracked, and some collapsed parapets. Tombstones were overturned and rotated. Maximum intensity felt in Arkansas was at Jonesboro, Osceola, Paragould, Piggott, and Pocahontas.

Fayetteville: 11/9 17:02:54.5 S–P 52 sec. Amp. 80 mm.

Reference: USEq, 1968 and USEq through 1970, Street et. al., Focal Mechanism No. 23.

1969

January 1   17:35   Central Arkansas

Instrumental epicenter placed at Ferndale, Arkansas south of Lake Maumelle. Felt over most of northern and central Arkansas. Felt at Rogers but not at Bentonville, at Van Buren, but not at Fort Smith. In central Arkansas felt at Prescott, Camden and Fordyce, but not beyond. The maximum felt effects were at Little Rock and North Little Rock where it was reported difficult to stand up. Walls and floors cracked; small objects shifted, overturned and fell; furniture shifted; tall buildings swayed; and mirrors and Venetian blinds swung. Felt in southern Missouri and at Memphis, Tennessee.

Fayetteville: Station not operating.

Reference: USEq, 1969, and USEq through 1970, Street et. al., Focal Mechanism No. 24.

1970

November 16 20:14 Northeastern Arkansas

Instrumental epicenter at Blytheville. Felt over northeastern Arkansas, northern Mississippi, western Tennessee and the west tip of Kentucky, Cairo, Illinois, and southeastern Missouri. In Arkansas felt as far south as Helena and as far west as near Batesville. At Keiser small objects fell from tables, furniture shifted and plaster cracked. Three wall electrical outlets burned wires. At Manila plaster cracked and fell. At Collierville, Tennessee a chimney cracked and plaster cracked and fell. Minor damage was reported at Blytheville, Earle, Egypt, Jonesboro, Luxora, and Tupelo, Arkansas.

Fayetteville: 11/17 02:15:01.2 Amp. 8 mm.

Reference: USEq, 1970, Street et. al., Focal Mechanism No. 27.

1971

April 13 8:01 Victoria, Arkansas

Not reported felt. Instrumental epicenter places it at Victoria southwest of Blytheville.

Fayetteville: 4/13 14:01:31.3 S–P 57 sec. Amp. 9 mm.

Reference: Preliminary Determination of Epicenter Cards

October 1 12:50 Northeast Arkansas

Instrumental epicenter at Lake City, Arkansas. Felt extensively in the northeast corner of Arkansas and scattered localities in Alabama, Tennessee, Kentucky, Indiana, Illinois and Missouri. At Lake City plaster and buildings cracked and at Sedgwick, Arkansas some concrete cracked. Intensity V at Bay, Black Oak, Brookland, Delaplaine, Lake City, Lunsford, Roseland, Sedgwick and Trumann.

Fayetteville: 10/1 18:50:27.5 S–P 26 sec. Amp. 36 mm.

Reference: USEq, 1971

1972

January 31 23:40 Northeast Arkansas

Instrumental epicenter at Datto, Arkansas. Maximum felt effects at Delaplaine, Biggers, Knobel, and Maynard. Walls cracked in concrete block building at Biggers and caused foundation cracks and cracks between concrete blocks at Delaplaine. Loud explosive noise heard at Biggers, Knobel and Maynard. Felt mainly in Randolph, Lawrence, Clay, and Greene Counties. Felt at Poplar Bluff, Missouri and southeastern Missouri and adjacent Kentucky.

Fayetteville: 2/1 05:42:53.7 S–P 37 sec. Amp. 90 mm.

Reference: USEq, 1972, Street et. al., Focal Mechanism No. 31.

March 29 14:38 Southeast Missouri

Instrumental epicenter in Tennessee across the river from Caruthersville, Missouri. In the bootheel of Missouri and adjacent Kentucky and Tennessee windows, doors, and dishes rattled, a few small objects overturned. Locally plaster was cracked, windows broken and floors buckled. In Arkansas felt at a few widely scattered localities as far as Sweet Home; no damage reported.

Fayetteville: 3/29 20:39:26.9 S–P 38 sec. Amp. 75 mm.

Reference: USEq, 1972, Street et. al., Focal Mechanism No. 32.

May 6 20:12 Blytheville, Arkansas

Felt at Blytheville and Lepanto, Arkansas and Finley, Tennessee.

Fayetteville: 5/7 02:13:05.7 S–P 49 sec. Amp. 27 mm.

Reference: USEq, 1972, Street et. al., Focal Mechanism No. 33.

1973

October 2 21:50 Arkansas-Tennessee Border

Instrumental epicenter west-southwest of Blytheville, Arkansas. Felt in northeast Arkansas, the bootheel of Missouri, and northwestern Tennessee.

Fayetteville: Not recorded.

Reference: USEq, 1973, Street et. al., Focal Mechanism No. 37.

October 9 14:15 Southeast Missouri

Instrumental epicenter at Marston, Missouri. "The shock affected a small area in Lake County, Tennessee and Fulton County, Kentucky but the full extent of the area was not determined."

Fayetteville: 10/9 20:16:25.2 Amp. 45 mm.

Reference: USEq, 1973, Street et. al., Focal Mechanism No. 38.

1974

January 7 19:12 Missouri-Tennessee

Instrumental epicenter places it at Cloverdale, Tennessee. Felt over a small area of western Tennessee, southeastern Missouri and a few towns in Illinois and Arkansas; no damage. In Arkansas only felt reports from Keiser and McDougal.

Fayetteville: 1/8 01:13:37.5 S–P 59 sec. Amp. 122 mm.

Reference: USEq, 1974

February 15 16:35 South Arkansas
16:50 main shock
16:54

Instrumental epicenters place these 8 to 14 miles south of Arkadelphia. One or more shocks were felt from Little Rock to Magnolia and from Texarkana to Tinsman. The only damage occurred in Whelen Springs where plaster cracked in some buildings during the main shock. A few small objects were shifted or shaken from shelves in Arkadelphia, Bluff City, Donaldson, Gurdon, and Whelen Springs.

Fayetteville: 2/15 22:36:25 Amp. 43 mm.
22:49:41.5 Amp. 80 mm.
22:54:14 Amp. 15 mm.

Reference: USEq, 1974

February 15-16 21:39 South Arkansas
03:43
03:44

Instrumental epicenters near Curtis, 12 miles south of Arkadelphia. None of these events are reported as felt.

Fayetteville: None recorded.

Reference: Preliminary Determination of Epicenter Monthly Report.

February 24 01:53 Northeast Arkansas

Instrumental epicenter at Lake City, Arkansas. Not reported felt.

Fayetteville: 2/24 07:53:45.2 S–P 41 sec. Amp. 4 mm.
Reference: Preliminary Determination of of Epicenter Monthly Report

March 4 08:24 Northeast Arkansas

Instrumental epicenter at Rivervale, Arkansas. Not reported felt.

Fayetteville: 3/4 14:25:53.5 Amp. 4 mm.
Reference: Preliminary Determination of Epicenter Monthly Report

April 3 17:05 Parkersburg, Illinois

Felt over all or parts of Arkansas, Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, Ohio, Tennessee, Virginia, and Wisconsin. Minor damage as cracked plaster, broken chimneys, and cracked windows in Illinois and Indiana. In Arkansas felt only at Hunter and Wilson.

Fayetteville: 4/3 23:06:37 Amp. 67 mm.

Reference: USEq, 1974

May 13 00:52 East Prairie, Missouri

Felt at a few scattered localities in a small area of Missouri, Arkansas, Tennessee, Kentucky and Illinois. At east Prairie the city swimming pool was badly damaged and plaster cracked in several buildings. In Arkansas only reported felt at McDougal.

Fayetteville: 5/13 06:53:20.7 S–P 60 sec. Amp. 48 mm.

Reference: USEq, 1974

December 12 23:04 Tucker-Coy area, Arkansas

Instrumental epicenter at Pettus, Arkansas. Felt mainly in Lonoke and Jefferson Counties with scattered felt reports from Little Rock to Dumas. No damage but residents were awakened and frightened.

Fayetteville: 12/13 05:04:37.7 S–P 33 sec. Amp. 57 mm.

Reference: USEq, 1974

December 13 04:13 Missouri-Arkansas Border

Instrumental epicenter near Rover, east of West Plains, Missouri. Not reported felt.

Fayetteville: Not recorded.

Reference: Preliminary Determination of Epicenter Monthly Report

December 25 07:21 Blytheville, Arkansas

Instrumental epicenter near Hightower, 11 miles south-southwest of Blytheville. Felt at Armorel and Blytheville; no damage.

Fayetteville: 12/25 13:22:37.9 S–P 42 sec. Amp. 5 mm.

Reference: USEq, 1974

1975

January 2 03:18:59.7 New Salem, Arkansas

Felt at Forrest City, no details available.

Fayetteville: 1/12 09:19:44.4 S–P 36 sec. Amp. 30 mm.

Reference: USEq, 1975

January 10 09:31:00.8 Pea Ridge Mine, Missouri

A mine blast of 300,000 pounds of Gelignite. Shock evaluated equal to a magnitude of 3.2 earthquake.

Fayetteville: 1/10 15:32:00.0 Amp. 6.8 mm.

Reference: USEq, 1975, Fayetteville Seis Sta. Bull. V24 No. 1

February 13 13:43:37.6 New Madrid, Missouri

Felt in Missouri, Tennessee, Kentucky and Illinois. Intensity V at Marston, Missouri.

Fayetteville: 2/13 19:44:55.2 S–P 57 sec. Amp. 20 mm.

Reference: USEq, 1975

June 13 16:40:27.2 New Madrid, Missouri

Felt in Missouri, Arkansas, Tennessee, and Kentucky. Maximum felt effect at Lilbourne, Missouri where many were frightened, trees and bushes shook, plaster cracked and fell; and at Marston, Missouri, where all felt and were frightened, furniture overturned and broke, small objects fell, and there were faint Earth noises. In Arkansas felt with Intensity III at Saint Francis and Wilson; and Intensity II at Success.

Fayetteville: 6/13 22:41:19.9 Amp. 47 mm.

Reference: USEq, 1975

August 20 3:14:16.6 New Madrid area

Instrumental epicenter at Risco, Missouri; not reported felt.

Fayetteville: 8/20 09:16:20.5 Amp. 2.1 mm.

Reference: Preliminary Determination of Epicenters Monthly

August 25 1:11:08.0 New Madrid area

Instrumental epicenter at Holland, Missouri. Not reported felt.

Fayetteville: 8/25 07:12:11.4 S–P 42 sec. Amp. 10 mm.

Reference: Preliminary Determination of Epicenters Card 41-75

1976

January 16 13:42:57 Northern Arkansas

Intensity V at Blanchard Springs Cavern where it was felt by all in the cave and rocks fell. Felt strongly 7 km north of Onia where trees and bushes were noticeably disturbed. Felt Intensity IV at Bull Shoals, Cotter, Fifty Six, Mountain View and Norfolk. Felt Intensity III at Mountain Home and Intensity II at Calico Rock, Salesville, and Sycamore Springs. Recorded at Fayetteville.

Reference: USEq, 1976

March 24 18:41:20.5 Northeast Arkansas

Felt over an area of 280,000 sq. km bounded by Centralia, Illinois; Hopkinsville, Kentucky; Nashville and Clifton, Tennessee; Birmingham, Alabama; Little Rock, Arkansas; and Jefferson City, Missouri. In Arkansas it was felt at Intensity VI at Bay (furniture moved, small objects broke) Biggers, Blytheville, Brookland, Bunker (plaster and drywall cracked), Cash, Datto, Decatur (ceiling tiles fell, some roof damage), Delaplaine, Dolph, Egypt, Hardy, Harrisburg (plaster cracked), Jonesboro (power blackout, telephone lines down, ceiling, walls and floor shook violently at State Police headquarters 7.6 m underground), Knobel (plaster cracked), Lake City, Lepanto (dry walls cracked), Luxora, Marked Tree (plaster cracked), McDougal, Minturn, Okean, Paragould (windows broken), Peach Orchard (dry walls cracked) Portia, Sedgwick, Smithville, Tomato, Trumann (dry walls cracked, ceiling tiles fell), Twist, Walnut Ridge (windows blown out) . . . Also felt with Intensity VI in Kentucky, Mississippi, Missouri, and Tennessee.

Fayetteville: 3/25 0:42

Reference: USEq, 1976

March 24 19:00:11.9 Northeast Arkansas

An aftershock of the preceeding. Felt at several towns.

Fayetteville: 3/25 1:00:30

Reference: USEq, 1976

May 22 1:40:46 New Madrid, Missouri

Felt Intensity V at Cooter and Steele, Missouri, and at Ellendale, Tennessee.

Possibly felt northeast of Blytheville in Arkansas.

Fayetteville: Not recorded.

Reference: USEq, 1976

September 25 8:06:56.0 Marked Tree, Arkansas

Felt Intensity V at Lepanto, Payneway (small objects moved), Trumann, Tyronza (small objects moved); Intensity IV at Marked Tree and Riverdale, Arkansas and Deering, Missouri; Intensity II at Hunter and Swifton, Arkansas. Also reported felt in Jackson County, Arkansas. Felt in southeast Missouri and northwest Tennessee.

Fayetteville: Recorded 9/25 14:07

Reference: USEq, 1976 and Earthquake Information Bulletin Vol. 9 No. 1

1977

June 2 17:29:10.4 Arkansas-Oklahoma Border

Felt Intensity VI at Board Camp (hair line cracks in exterior walls, cracked chimneys, small objects and light furniture shifted, felt by many) and Hatfield (sidewalks slightly cracked, foundations cracked, buildings trembled, felt by many). Felt Intensity V at Black Springs, DeQueen, Gillham, Mena, Saratoga, and Umpire; Intensity III at Grannis and Wickes; and Intensity III at Langley.

Reference: USGS Circular 788-B Earthquakes in the United States, April-June, 1977

1978

August 30 18:31:01.7 New Madrid, Missouri

Felt with Intensity V at Dyersburg, Tennessee. Also felt with Intensity III at Bogota, Firiley, Lennos, Minston and Nauvoo, Tennessee, and also at Caruthersville, Missouri.

Reference: Earthquake Information Bulletin, Vol. 11, No. 1, 1979

September 23 6:35:57 Southeast Arkansas

Located approximately 15 km north of Wilmer where Intensity V effects were felt.

Reference: Earthquake Information Bulletin, Vol. 11, No. 2

September 28 15:56:25.1 Missouri-Arkansas Border

Instrumentally determined, not felt.

Reference: Preliminary Determination of Epicenters Card 27P-78

1979

February 2 23:31:9.3 Arkansas

Felt at Blytheville.

Reference: Preliminary Determination of Epicenters Card 3-79