Name:________________
Date:________________

# 10 Locating Earthquakes

## 10.1 Introduction

Because of convective motions in the mantle of the Earth, which are driven by heat transfer from the hotter interior regions up through the cooler crust, stresses build up in the outer rigid crust. Sometimes these stresses are relieved by abrupt slippages, or *earthquakes*, that generate shock waves that propagate outward from the quake site. Earthquakes can result in loss of lives and considerable damage to buildings as well as transportation and communication systems.

The actual slippage in Earth's crust usually occurs miles below the surface. The exact site is called the *focus* of the earthquake. The point on the Earth's surface directly above the focus is called the *epicenter*.

The shock waves generated by the quake are called *seismic* waves (from the Greek word "seismos," which means to shake). There are three types of waves. The first type is called **L waves**, which travel only on the Earth's surface and are similar to water waves on the ocean. Next are **P waves**, which are compressional waves, and can travel through gases, liquids or solids. The motion associated with **S waves**, which are shear waves, is perpendicular to the direction of motion. The S waves dissipate quickly in liquids and gases.

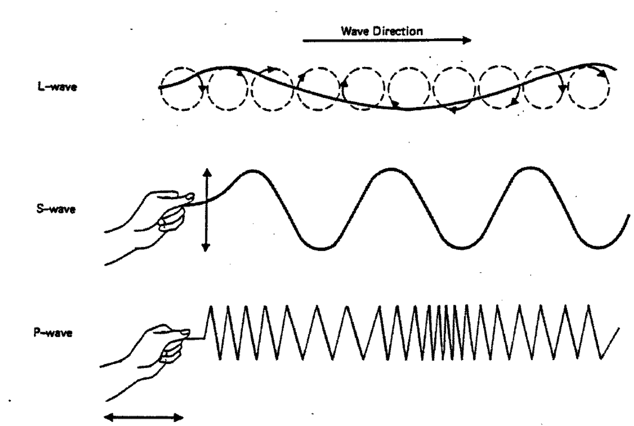



**Figure 6-17.** ***Three Types of Waves.*** Earthquakes produce three types of waves. L-waves travel on the earth's surface. S-waves and P-waves travel through the earth.

Figure 10.1: Different types of waves.

The P waves travel almost twice as fast as S waves, thus the P wave shock will arrive at a remote station before the S wave shock will. A *seismometer* is an instrument that consists of a massive base and a detector that picks up seismic waves. If the speed of the waves through the local crust is known and you have a seismometer so you can record the shocks, then at any single station you can determine how far you are from the focus of the quake.

Use the following graph to determine the average speed of the P and S waves for a typical Earth crust. Assume that we are going to be dealing with *shallow earthquakes* in the state of New Mexico, *i.e.,* those that have depths of 20 km or less. Put the wave speed values you read off of Figure 10.2 into Table 10.1. (**4 points**)

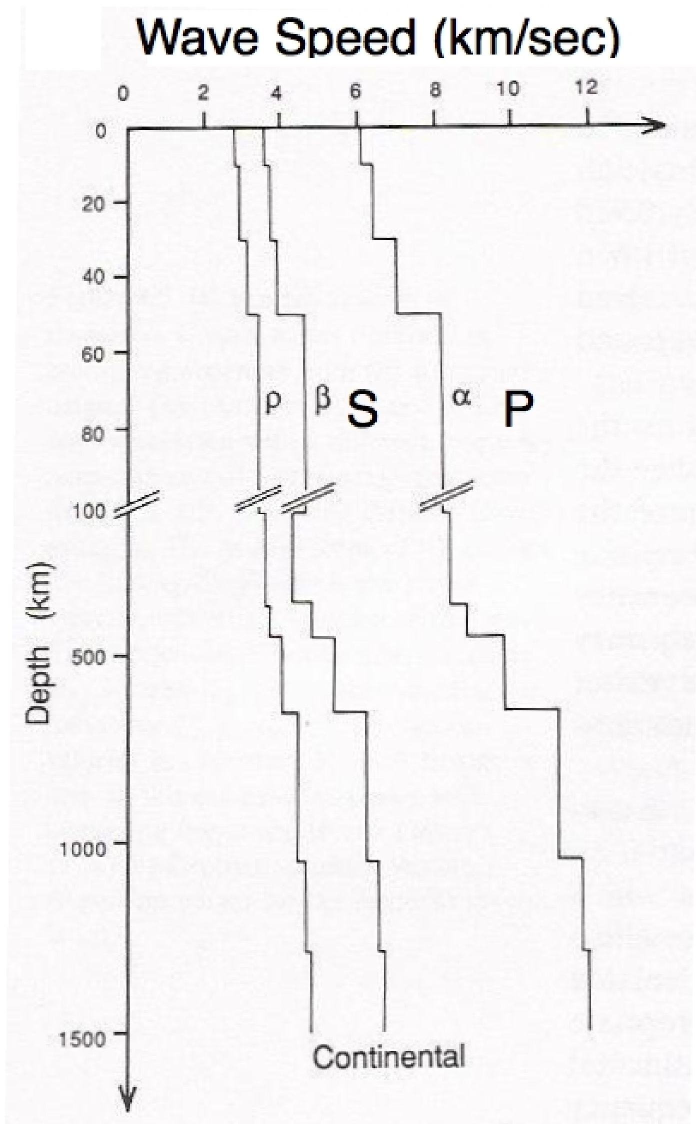



Figure 10.2: Wave speeds as a function of depth.

| Type of Wave | Speed of Wave (km/sec) |
|---|---|
| P Wave | |
| S Wave | |

Table 10.1: Comparison of P and S wave travel times.

## 10.2 Locating an Earthquake

### 10.2.1 Finding the Distances

Consider the problem of locating a small local quake. We will use real earthquake data from seismic stations in Alamogordo, Albuquerque, El Paso, Las Cruces, Santa Fe, and Socorro. The data for five different earthquakes that took place in New Mexico can be found at the end of this lab. Choose an earthquake for your group to analyze (tell your TA, as they might want different groups to do different earthquakes!). Write down which earthquake you are analyzing (numbers 1-5) in the space below:

**Earthquake #:** ________

Copy the P and S wave onset times from your data sheet for your earthquake into Table 10.2.

Table 10.2: P and S wave arrival times at six seismic stations.

| Station | Onset of P wave | Onset of S wave | $\delta$t (sec) | dist. to focus (km) |
|---|---|---|---|---|
| Alamogordo | | | | |
| Albuquerque | | | | |
| El Paso | | | | |
| Las Cruces | | | | |
| Santa Fe | | | | |
| Socorro, NM | | | | |

$\delta t$ ("delta-t") is the difference between the arrival time of a P wave and the arrival time of an S wave at any given seismic station. Calculate $\delta t$ for each of the six stations and place these values in Table 10.2. (**12 points**)

Now we must calculate the distance that the wave traveled from the earthquake's focus to each recording station. If $X$ is the distance between the focus and the seismograph and $v_P$ = *speed of P wave* and $v_S$ = *speed of S wave*, then:

$$\frac{X}{v_P} = t_P = time\ of\ travel\ for\ P\ wave \tag{9}$$

and

$$\frac{X}{v_S} = t_S = time\ of\ travel\ for\ S\ wave. \tag{10}$$

Since $\delta t = t_S - t_P$, substituting from Equations (1) and (2) above gives us

$$\delta t = \frac{X}{v_S} - \frac{X}{v_P}. \tag{11}$$

Equation (3) can be rewritten as

$$\delta t = \frac{(v_P \times X) - (v_S \times X)}{v_S \times v_P} \tag{12}$$

If we factor out $X$, multiply both sides by $v_P \times v_S$, and divide by $v_S - v_P$, we find that the distance between the earthquake focus and any given seismic station is

$$X = \delta t \times \frac{v_P \times v_S}{v_P - v_S} \tag{13}$$

Compute the distances to the six stations using Equation (5) and insert these values into Table 10.2 (**12 points**).

### 10.2.2 Determining the Location

Now you will use the map to determine the site of the quake. First, figure out the number of centimeters that correspond to 1 km by measuring the scale bar on your map (lower left corner of map) with a ruler.

140.8 km = ________ cm

1 km = the above number /140.8, = ________ cm = $S$, the scale factor

Copy the distances from Table 10.2 into the second column of Table 10.3. Then convert the true distances in Table 10.3 from km to *scaled distances* in cm:

scaled distance = true distance × $S$

Insert these numbers into Table 10.3 (**6 points**).

Set the compass for each scaled distance and place the point of the compass at the station and draw an arc on the map located at the end of the lab (**10 points**). When you are done, you will use your results in conjunction with the information on the last page of the lab regarding the geology of New Mexico to answer the following questions.

Table 10.3: Distance from each seismic station to earthquake focus.

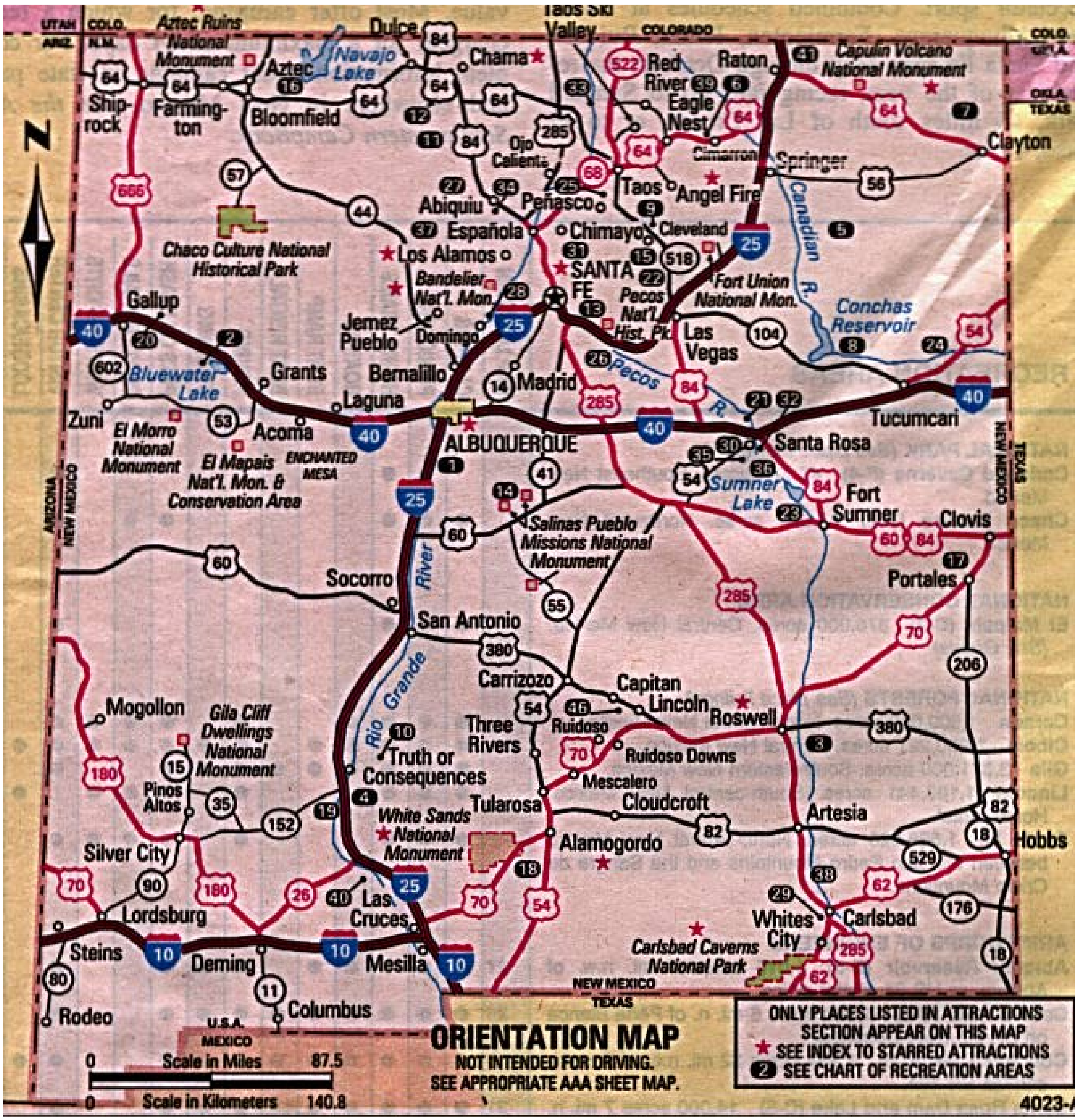
| Station | Dist. to focus (km) | Scaled Dist. to focus (cm) |
|---|---|---|
| Alamogordo | | |
| Albuquerque | | |
| El Paso | | |
| Las Cruces | | |
| Santa Fe | | |
| Socorro, NM | | |

## 10.3 In-Lab Questions

1. What was the site of this local quake? What might be the cause of small quakes in this region? (**10 points**)

2. What is your best estimate of the time the quake occurred? (**5 points**)

3. Based on the size of the intersecting region of your diagram, what can you say about the depth of the quake? (**6 points**)


Aztec Ruins National Monument
Dulce
Navajo Lake
Aztec
Chama
Taos Ski Valley
COLORADO
Red River
Raton
Capulin Volcano National Monument
Ship-rock
Farming-ton
Bloomfield
Eagle Nest
Clayton
Ojo Caliente
Cimarron
Springer
Taos
Angel Fire
Abiquiu
Peñasco
Española
Chimayo
Cleveland
Chaco Culture National Historical Park
Los Alamos
SANTA FE
Canadian R.
Bandelier Nat'l. Mon.
Fort Union National Mon.
Gallup
Jemez Pueblo
Domingo
Pecos Nat'l. Hist. Pk.
Las Vegas
Conchas Reservoir
Bluewater Lake
Grants
Bernalillo
Madrid
Pecos R.
Laguna
Zuni
El Morro National Monument
Acoma
ALBUQUERQUE
Tucumcari
El Mapais Nat'l. Mon. & Conservation Area
ENCHANTED MESA
Santa Rosa
Sumner Lake
Fort Sumner
Clovis
Salinas Pueblo Missions National Monument
Socorro
River
Portales
San Antonio
Carrizozo
Capitan
Lincoln
Roswell
Mogollon
Gila Cliff Dwellings National Monument
Rio Grande
Three Rivers
Ruidoso
Truth or Consequences
Ruidoso Downs
Mescalero
Pinos Altos
Tularosa
Cloudcroft
Artesia
White Sands National Monument
Silver City
Alamogordo
Hobbs
Lordsburg
Las Cruces
Whites City
Carlsbad
Steins
Deming
Mesilla
Carlsbad Caverns National Park
NEW MEXICO
TEXAS
Rodeo
Columbus
U.S.A.
MEXICO
ARIZONA
NEW MEXICO
ORIENTATION MAP
NOT INTENDED FOR DRIVING.
SEE APPROPRIATE AAA SHEET MAP.
ONLY PLACES LISTED IN ATTRACTIONS SECTION APPEAR ON THIS MAP
SEE INDEX TO STARRED ATTRACTIONS
SEE CHART OF RECREATION AREAS
Scale in Miles
0
87.5
Scale in Kilometers
0
140.8
N

Name:________________________________
Date:________________________________

## 10.4 Take Home Exercise (35 points total)

On a separate sheet of paper, answer the following questions:

1. When large earthquakes occur, stations within a few thousand km of the focus detect both P and S waves. On the opposite side of the Earth only P waves are detected. Review the nature of the P and S waves and argue that there is a molten region at about 3500 km from the center of the Earth (compared to the Earth's 6378 km radius). [A figure will be helpful here.] How might you detect a smaller solid central core if there were one? (**20 points**)

2. a) Clearly describe how you would design a spacecraft mission to Mars to determine whether or not Mars has molten metal in its core, including what properties of Mars you would want to measure. b) Would you want one or more than one lander? c) If you could only have an orbiter mission to Mars (no landers), what measurements would you want it to make to help you determine whether or not Mars has a molten metal core. [Hint: the measurement will *not* be the reflected sunlight or blackbody radiation.] (**15 points**)

## 10.5 Possible Quiz Questions

1. What is an earthquake?
2. How are earthquakes generated?
3. What is an "L-wave"?
4. What is an "S-wave"?
5. What is a "P-wave"?
6. Do all the different kinds of waves travel at the same speeds?

## 10.6 Extra Credit (ask your TA for permission before attempting, 5 points)

Below is a brief summary about the geology of New Mexico. Using this guide, and *additional research*, describe why we have earthquakes in New Mexico. Why are the earthquakes in New Mexico usually so much smaller (less intense) than those that are common to California?

*This Geological summary is from the 1990 New Mexico Magazine Vacation Guide.*

# Geology

New Mexico's geology is as diverse and colorful as its culture, history and people. From the low-lying flatlands of the south to the soaring peaks of the northern mountains, the state's terrain climbs 10,000 feet in altitude creating a landscape of dramatic contrasts.

The creation of New Mexico's present landscape began some 70 million years ago during the Cenozoic era. About this time the Rocky Mountains were born during the Lara-mide Revolution, a general uplifting of the Earth's crust.

The ancient seas that covered most of New Mexico in earlier times slowly disappeared, and along with them went the dinosaurs and abundant marine life of the Triassic, Jurassic and Cretaceous periods.

Volcanic activity has played an integral role in shaping New Mexico's terrain. Evidence of centuries of volcanism is apparent across the state. Rising well over 1,700 feet above the surrounding land, Shiprock is a volcanic neck–the core of all that remains of a long-eroded volcano.

Valle Grande, located in the center of the Jémez Mountains, is one of the world's largest calderas. The violent eruption that created it released over 75 cubic miles of molten rock, which slowly cooled as it flowed over the land. Today the crater contains 176 square miles of meadow land where wildflowers bloom and cattle graze peacefully.

To the south, Little Black Peak in Valley of Fires State Park erupted barely 1,000 years ago, emitting what is now 44 miles of ropey pa hoe hoe lava flows, more than 150 feet thick in some places. As it spread and cooled, the lava formed domes, tubes, caves and fissures. This area is among the most recent and best preserved examples of such lava flows in the continental U.S.

Seismic activity continues to alter the land. Tension in the Earth's crust along a pair of parallel fault lines running down the center of New Mexico has resulted in the formation of the great Rio Grande Rift Valley. This huge trough, which contains the Rio Grande, is 30 miles across at Albuquerque and widens considerably to the south.

Many of the state's mountains, including the Sandìa, Manzano and Sacramento ranges, were formed from fault blocks that were tilted and raised as the Earth's crust was uplifted.

In New Mexico's arid environment, water is a scarce and precious resource that is, nevertheless, a powerful force in the sculpting of geological features.

Circulating underground water dissolves salt, gypsum and limestone deposits to form subterranean realms such as Carlsbad Caverns, one of the largest cave systems in the world.

When the roofs of such caverns collapse, sink holes are formed and lakes develop. Bottomless Lakes State Park near Roswell plays on a harmless exaggeration of the depth of these unique features, the deepest of which is about 90 feet.

Winds blowing in from gypsiferous Lake Lu-cero have built up what is now White Sands National Monument. Here, sparkling snow-white sand crests in dunes up to 50 feet high. The 275 square-mile monument contains more than 8 billion tons of gypsum and is the largest dune field of its kind in the world.

### Earthquake # 1

Since 1973 (when recording of earthquakes in the US became more precise and organized), the three most powerful earthquakes to hit New Mexico were all of magnitude 5.0. This earthquake, the first of these three, occurred during the night of January 4, 1976. In locations near the earthquake's epicenter, the event was felt by everybody. Only buildings in poor repair suffered significant damage. Most other damage was on the level of things falling off of shelves.

Table 10.4: Data for Earthquake 1.

| Reporting Station | P-wave Onset Time (MST) | S-wave Onset Time (MST) |
|---|---|---|
| Alamogordo | 23:24:37.1 | 23:25:22.4 |
| Albuquerque | 23:24:01.4 | 23:24:21.1 |
| El Paso | 23:24:52.3 | 23:25:48.5 |
| Las Cruces | 23:24:41.4 | 23:25:29.8 |
| Santa Fe | 23:24:08.2 | 23:24:32.8 |
| Socorro | 23:24:12.2 | 23:24:39.6 |

### Earthquake # 2

This earthquake, the second of the three most powerful felt in New Mexico, occurred during early in the morning on January 2, 1992. This earthquake was felt by most people in the area, but did not cause significant damage, aside from knocking over a few small objects like vases.

Table 10.5: Data for Earthquake 2.

| Reporting Station | P-wave Onset Time (MST) | S-wave Onset Time (MST) |
|---|---|---|
| Alamogordo | 04:46:20.6 | 04:46:52.9 |
| Albuquerque | 04:46:49.0 | 04:47:41.6 |
| El Paso | 04:46:28.9 | 04:47:07.1 |
| Las Cruces | 04:46:32.2 | 04:47:12.8 |
| Santa Fe | 04:46:50.0 | 04:47:43.4 |
| Socorro | 04:46:41.3 | 04:47:28.3 |

## Earthquake # 3

Of the three that have been at magnitude 5.0, this earthquake is the most recent: during the afternoon of August 10, 2005. Reports indicate that this earthquake was powerful enough to be felt, and caused clearly visible effects (like sloshing liquid, wobbling furniture, parked cars rocking), but no significant damage.

Table 10.6: Data for Earthquake 3.

| Reporting Station | P-wave Onset Time (MDT) | S-wave Onset Time (MDT) |
|---|---|---|
| Alamogordo | 16:09:38.0 | 16:10:31.9 |
| Albuquerque | 16:09:05.8 | 16:09:36.7 |
| El Paso | 16:10:00.0 | 16:11:09.7 |
| Las Cruces | 16:09:51.6 | 16:10:55.4 |
| Santa Fe | 16:08:50.7 | 16:09:10.9 |
| Socorro | 16:09:23.5 | 16:10:07.1 |

## Earthquake # 4

This earthquake, one of the most powerful New Mexico earthquakes in recent history, was of magnitude 4.8. It occurred on the morning of January 29, 1990. In locations near the earthquake's epicenter, the event was felt by everybody. Only buildings in poor repair had significant damage. Most other damage was on the level of broken dishware, or things falling off of shelves.

Table 10.7: Data for Earthquake 4.

| Reporting Station | P-wave Onset Time (MST) | S-wave Onset Time (MST) |
|---|---|---|
| Alamogordo | 06:16:42.3 | 06:17:05.0 |
| Albuquerque | 06:16:22.7 | 06:16:31.3 |
| El Paso | 06:17:00.1 | 06:17:35.5 |
| Las Cruces | 06:16:49.7 | 06:17:17.7 |
| Santa Fe | 06:16:37.1 | 06:16:56.0 |
| Socorro | 06:16:18.4 | 06:16:24.0 |

## Earthquake # 5

This earthquake, among the most powerful New Mexico earthquakes in recent history, was of magnitude 4.7. It occurred during the night of November 28, 1989. This earthquake was felt by most people in the area, but did not cause significant damage, aside from knocking over stuff on shelves.

Table 10.8: Data for Earthquake 5.

| **Reporting Station** | **P-wave Onset Time (MST)** | **S-wave Onset Time (MST)** |
|---|---|---|
| Alamogordo | 23:55:10.2 | 23:55:32.9 |
| Albuquerque | 23:54:50.6 | 23:54:59.2 |
| El Paso | 23:55:27.9 | 23:56:03.3 |
| Las Cruces | 23:55:17.5 | 23:55:45.5 |
| Santa Fe | 23:55:05.0 | 23:55:24.0 |
| Socorro | 23:54:46.3 | 23:54:51.8 |