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SEISMIC ZONES CONFORMING TO NAFTA

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ABSTRACT

Earthquakes are a recognized threat to life safety and buildings. To help prevent loss of life and reduce damage to structures, special detailing requirements are imposed by the Building Codes. These requirements are based on the seismic exposure in which the building is located.

Seismicity in North America has been very active and this paper will highlight the seismic areas of the three countries conforming to NAFTA; Canada, United States and Mexico. Seismic exposure maps are provided which are useful providing an overall picture of the geographical patterns of earthquake damage, including the influence of soils and local geology.

INTRODUCTION

We expect anything to move, but not the earth! The world is more vulnerable to earthquake disaster than ever before due to growing population, its concentration, increased economic and capital investment, and the fragility of lifelines. Every significant earthquake has the potential to provide a valuable learning experience which, when studied, can help to prevent future earthquake disasters everywhere.

Although valuable information has been accumulated in destructive North American seismic events, such as Miramichi, Canada, 1982 (Magnitude of 5.9 Richter Scale); Nothridge, California, 1994 (Mag. 6.7); Mexico City, Mexico, 1985 (Mag. 8.1); and many others, more should have been learned. For each seismic event, however, the accumulated statistical data significantly increased the understanding of earthquakes. Unanticipated seismic accelerations and ground movements demonstrate the need to consider the strength and flexibility of buildings relative to ground motion.

Earthquakes provide many educational opportunities. New knowledge has been obtained and continuing research will provide additional knowledge. The earthquakes also demonstrate that there are gaps in our knowledge and that more must be learned. There is a need for better preparation for learning from earthquakes and this preparation must be made in advance of the seismic events. Technical understanding could be much enhanced by stronger international cooperation between NAFTA countries, Canada, United States and Mexico.

EARTHQUAKES

Strong earthquakes are usually caused by significant movement on a fracture of the earth's crustal rocks. This generally takes the form of sliding along a rupture plane called a *fault*, in response to a relief of strain.

It is common for earthquakes to occur repeatedly along the same fault over a long period of years. Major faults like the San Andreas in California are generally thought to be the boundaries between two differentially moving crustal plates.

In the time of the ancient Greeks it was natural to link the Aegean volcanoes with the earthquakes of the Mediterranean. As time went on, however, it became clear that most damaging earthquakes were, in fact, not caused by volcanic activity.

A more coherent explanation of the majority of earthquakes is in terms of what is called plate tectonics. The basic idea is that the Earth's outermost part (lithosphere) consists of several large and reasonably stable slabs called plates (Figure 1). Each plate extends to a depth of about 80 km (50 miles).

Moving plates of the Earth's surface provide an explanation for a great deal of the seismic activity of North America. Collisions between adjacent lithospheric plates, destruction of a slablike plate as it descents, or subducts, into dipping zone beneath island arcs, and spreading along mid-oceanic ridges are all mechanisms that produce significant straining and fracturing of crustal rocks. Thus, earthquakes in these tectonically active boundary regions are called plate-edge earthquakes. The very hazardous shallow earthquakes of Western Canada, California in the United States and the Southern part of Mexico are of plate-edge type.

As the mechanics of the lithospheric plates becomes better understood, long-term predictions may be possible for plate-edge earthquakes. For example, many plates spread toward the subduction zones at rates of 2-5 cm (1-2 inches) per year. Therefore in active arcs such as near the Aleutian and Japanese islands and subduction zones such as in Chile and western Mexico, there is a large amount of statistical information associated with earthquake activity.

While the simple plate-tectonic theory is an important one for a general understanding of earthquakes, it does not explain all seismicity in detail, for within continental regions - away from the boundaries - large, devastating earthquakes sometimes do occur. These intraplate earthquakes can be found on nearly every continent.

Such major internal seismic activity indicates that lithospheric plates are not rigid or free of internal rupture. The occurrence of intraplate earthquakes makes the prediction of earthquake occurrence difficult in many regions where there is a significance seismic risk.

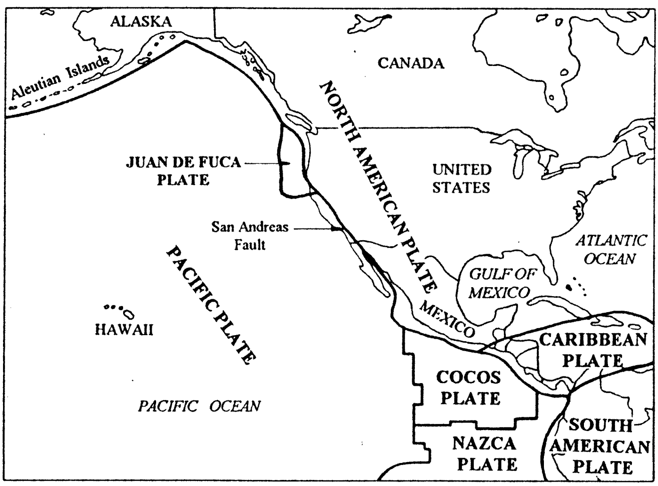

Figure 1 Earthquake plates of North America

In the case of the San Andreas Fault, the oceanic (West) plate is moving north with respect to the continental (East) plate. Where these two plates impinge at the fault, movements tend to be "jerky" as the plates edges alternately stick and slip. The ultimate cause of the movement of the crustal plates is related to tectonic processes in the earth's mantle beneath the crust.

When the location of all large North American earthquakes are plotted on a map (Figure 2) it is readily apparent that the majority occur in zones or "belts". Among these, The Pacific belt is responsible for 90 percent of the world's earthquakes.

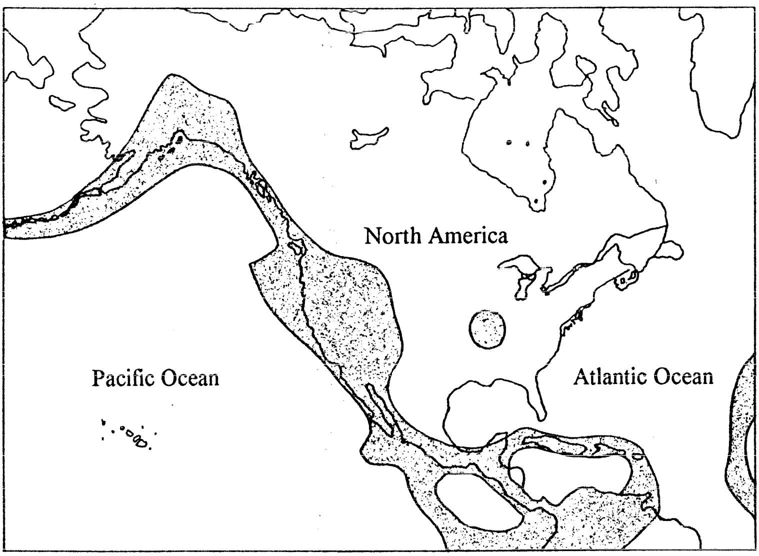

Figure 2 Earthquakes belts of North America

SEISMIC REGIONS IN CANADA

Since earthquakes occur on a geological rather than a human scale, most Canadians tend to shrug them off as improbable and therefore ignorable events. Yet, even within the limited period of recorded history in Canada there have been several major earthquakes. For example, the St. Lawrence earthquake in February, 1925 (Mag. 7.0) was felt strongly over a large area of Eastern Canada and the New England States. Although no one was injured, considerable damage was caused in a narrow belt covering both sides of the St. Lawrence River and extending from Trois Rivieres to Shawinigan Falls. Other important events in Eastern Canada were the Timiskaming earthquake in Western Quebec in 1935 (Mag. VI Mercalli scale) and the Cornwall-Massena earthquake on the upper St. Lawrence River in 1944 (Mag. VIII Mercalli scale).

In the West, the coastal region of Canada forms part of the Pacific earthquake belt which includes such seismically active regions as Alaska, California, Mexico, Nicaragua, Chile, New Zealand and Japan. Earthquakes have caused some damage at locations on Vancouver Island and on the Queen Charlotte Islands. In recent years special interest has focused on the seismic exposure in various parts of northern Canada because of proposed resource development.

The seismic map of Canada delineates the various seismic zones in terms of probable severity of ground motion that may occur in future earthquakes.

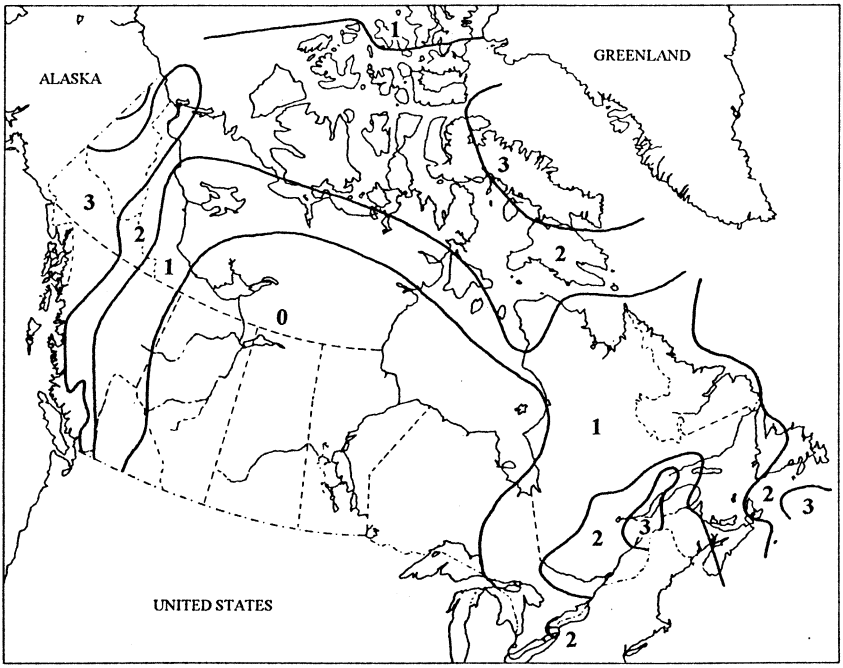

Figure 3 Seismic zoning map of Canada: Zone 0 - negligible; Zone 1 - small; Zone 2 - moderate; Zone 3 - greatest.

The Canada seismic zone map was developed primarily as a guide to those concerned with the design and construction of buildings. Some regions, for example the Prairies, have a record of limited seismic activity and thus the probability of damage in a future earthquake is very low (Zone 0), while other regions have experienced serious earthquakes in the past and this is reflected in the highest risk zone (Zone 3).

As Canada has not experienced a major destructive earthquake in recent decades, increasing attention has been focused on the vulnerability of essential lifeline services, both within buildings and throughout urban centers. Included are the power lines, water supplies, sewage disposal, communications, oil and gas pipeline and transportation facilities. Interruption of such services in a period of crisis can pose severe hardship to a community and a threat to the health and safety of the Canadian population. In addition to providing adequate strength and ductility to resist ground motion, it may be advisable to introduce multiple paths or loops in an infrastructure distribution network in order to provide alternate paths of supply. This limits the regions that would be affected by a failure or interruption at one point of a network.

Lessons learned from major destructive earthquakes in Mexico and the United States are being adapted to local geology, engineering practice and economic and social conditions.

Observations are complemented by theoretical and experimental studies carried out in design offices, universities and governmental laboratories. Ultimately they may be utilized by regulating bodies in the form of improved design requirements.

Large earthquakes have occurred in areas to the St. Lawrence River, on the West Coast and in the northern regions of Canada and can be expected again. In order to limit the risk of great damage it is prudent to anticipate the consequences of a projected seismic event and to employ principles of seismic resistant design.

SEISMIC REGIONS OF THE UNITED STATES

Approximately 39 American states are at some degree of seismic risk and those states are not always located directly above an area where tectonic plates rub against one another. Earthquakes can occur virtually anywhere, at any time, and exhibit a wide variety of seismic peculiarities.

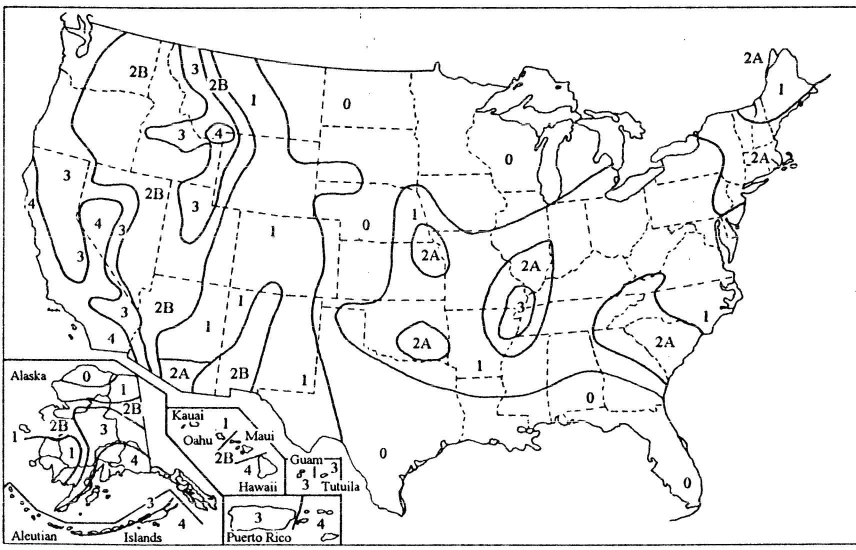

Figure 4 Seismic zone map of the United States: Zone 0 - no damage; Zone 1 - minor damage; Zone 2 - moderate damage; Zone 3 - major damage; Zone 4 - those areas within Zone 3 determined by the proximity to certain major fault systems.

There are no areas in the United States were soil conditions are as unique and potentially troublesome as those, for example, in Mexico City. Perhaps for this reason, scientists are reluctant to speculate on the possibility that such disaster (Mexico City earthquake, 1985) could happen here. There are, however, numerous areas in the United States where construction has taken place on filled-in lakes and bays, as well as areas where buildings stand on deep clay.

In a typical California earthquake the ground motions usually dampen rapidly. There may be 10 to 20 seconds of strong ground motion, but it would not be as intense as the ground motions that struck Mexico City in 1985 (Mag 8.1). California would survive a similar earthquake due simply to more stable soil conditions. Although an important factor in seismic activity, the duration of earthquakes is not weighed as heavily in the United States seismic design as it is in other parts of the world.

The following are a brief descriptions of the seismicity or earthquake activity of the various regions of the United States.

Northeastern Region: The northeastern region of the country contains zones of relatively high seismic activity. New York and Massachusetts have experienced numerous shocks, several quite severe. This region also is affected by large earthquakes originating in adjacent Canada, principally in the St. Lawrence River Valley.

Eastern Region: With the exception of 1886 Charleston, South Carolina, earthquake (Mag. X Mercalli scale), this region has a moderate amount of low-level seismic activity. Earthquakes occur throughout the region and the axis of principal activity roughly parallels to the Atlantic coast.

Central Regions: The upper Mississippi and Ohio Valleys are regions of relatively frequent earthquakes. Three of the great earthquakes of recorded history occurred along the New Madrid Fault in the Upper Mississippi region in 1811 and 1812 (Mag. 7.2, 7.1 and 7.4). Grave damage was prevented in this area only because it was sparsely settled. The extent and severity of land-form changes from these shocks have not been equaled by any other earthquake in the contiguous United States. Surprisingly, the little known New Madrid Fault is larger than the world famous San Andreas Fault.

Western Mountain Region: Montana, Utah and Nevada have been subjected to earthquakes of considerable severity and there is a region in Mexico, just south of the U.S.-Mexico border, which has had one major earthquake and many minor ones. A quake-related danger of considerable importance was evidenced in the 1959 Montana earthquake (Mag. 7.1) when a great avalanche claimed 28 lives and formed a barrier which blocked the Madison River, creating Hebgen Lake.

Washington and Oregon: From 1841 to 1970, many earthquakes of intensity 2 or greater centered in Washington and Oregon. Other quakes were felt, but they were centered either offshore in the Pacific, in British Columbia to the north or in adjacent states. Most of the earthquake activity occurs in the western part of the region, with the stronger shocks in the area of Puget Sound.

Alaska: Few of the Alaska shocks have caused severe damage because of the absence of large population centers. Seismic activity is separated into two zones. One zone, approximately 325 km (200 miles) wide, extends from Fairbanks through the Kenai Peninsula to the Near Islands. The second zone begins north of Yakutat Bay and extends southeastward to the west coast of Vancouver Island. The greatest earthquake in Alaska occurred on March, 1964 (Mag. 8.4) with an estimated duration about 2½ to 4 minutes.

California and Western Nevada: Earthquakes in California and western Nevada represent approximately 90 percent of the seismic activity in the contiguous United States. The majority of these shocks occur at relatively shallow focal depths, which partly accounts for the greater violence of earthquakes in the region compared with those occurring in the central or eastern United States. The principal fault in this area - the San Andreas Fault - extends over 1,000 km (600 miles) through California, from near the Salton Sea in Southern California northwest to Shelter Cover in Humbolt County (Figure 5). Movement along this fault was responsible for the great earthquakes in 1857 near Fort Tejon (Mag. 8+) and for the 1906 San Francisco shock (Mag. 8.3), as well as for many shocks of lesser magnitudes.

Hawaii: Seismic activity centers on the island of Hawaii, and much of it is associated with volcanic processes. However, the stronger shocks that are sometimes felt throughout the islands are of tectonic origin. The greatest known Hawaiian earthquake, in August 1951 (Mag. 6.8-7.0), was extremely violent and destructive, considering the sparsely settled nature of the islands. Shocks north of Hawaii are often felt strongly on the islands of Maui, Lanai and Molokai.

① **SAN ANDREAS FAULT** is the most publicized rift in California. It is by far the longest in the state, and it annually produces dozens of earthquakes.

② **HAYWARD FAULT**, despite its distinctive name, is really a branch of the San Andreas Fault.

③ **SIERRA NEVADA FAULT**. The Owens Valley branch of the system was responsible for the 1872 quake (magnitude 8.3 Richter scale) - the largest in California's recorded history.

④ **WHITE WOLF FAULT** is a short, relatively insignificant fault that unexpectedly moved in 1952 to cause a major quake in the Arvin-Tehachapi area (magnitude 7.7 Richter scale).

⑤ **GARLOCK FAULT** is the second largest fault in the state, and has made several contributions to the landscape, including the mountain ranges that form the northern edge of the Mojave Desert.

⑥ **SANTA YNEZ FAULT** is the largest of a group of related breaks that form a large seismic area around the Santa Barbara channel. An earthquake of 6.3 in 1925 was originated in this fault.

⑦ **SAN FERNANDO FAULT**, very similar to White Wolf Fault, was responsible for the devastating 1971 San Fernando earthquake (magnitude 6.6 Richter scale).

⑧ **NEWPORT-INGLEWOOD FAULT**, if there were any doubts about activity in this fault, they were dispelled in 1933, when the disastrous 6.3 Long Beach earthquake rattled the coast.

⑨ **SAN JACINTO FAULT** is part of the San Andreas Fault - indeed, it may be the most active branch.

⑩ **IMPERIAL FAULT** is another branch of the San Andreas Fault.

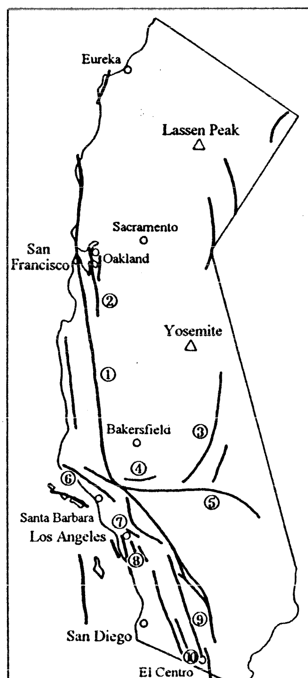

Figure 5 Significant faults in California

Puerto Rico Region: Many earthquakes have been felt in Puerto Rico since the settlement of the island by Europeans and several of the shocks have resulted in severe property damage. There is much geologic and topographic evidence that earthquakes have been of relatively frequent occurrence in this region for thousands of years.

The most important point to be made in any consideration of future earthquakes in the United States is that fault activity will continue for countless centuries. And, as long as there are fault movements, there will be earthquakes.

As industrial, commercial, and residential developments continue to increase in the United States, with population centers spreading in ever-widening circles, the significance of these inevitable earthquakes also increases. Many areas which were relatively uninhabited during the major earthquakes of the first part of this century are now industrial centers or are covered with great housing subdivisions. And if an earthquake of only 6.7 magnitude can cause billions of dollars in damage (Northridge, CA 1994), the potential destructiveness of much larger quakes above 8.0 magnitude that may hit heavily developed areas is awesome. The surface rupture of the 1906 earthquake (Mag. 8.3) ran through miles of unpopulated mountain regions on the San Francisco Peninsula. A similar earthquake today would crack the ground along hundreds of residential streets, and millions of people now living within 50 km (30 miles) of the fault line would be hit by tremendous shock waves.

SEISMIC REGIONS OF MEXICO

Mexico lies close to the region called the Middle American Trench. This area resides at the point where the Cocos Plate is thrust beneath the North American Plate. Activity in the Trench has traditionally produced the largest and most dangerous earthquakes in North America. Yet, the earthquake that hit Mexico City in 1985 (Mag. 8.1) originated in the Guerrero Seismic gap portion of the trench, an area which has shown no seismic activity for the last 150 years. Scientists expected activity in the gap, and were about halfway through the installation of sophisticated tracking stations when the earthquake struck.

Mexico has a history of lively seismic activity. The Spaniards provided the first Western account of a Mexican earthquake in the fifteenth century. The country has suffered through over 25 major earthquakes during the course of the 20^{th} century alone and some experts believe that the one that struck Mexico City in September, 1985 was the worst to hit the country within the last 100 years.

The southwestern coast of Mexico is a particularly active seismic region due to the interaction of the Cocos Plate and the North American Plate. The Mid-American Trench, parallel to the coast offshore, is presumed to be the subduction zone where the Cocos Plate is actively under-thrusting the North American Plate. Two major tectonic faults have been located in the mountain range parallel to the submarine trench.

Various investigators have proposed seismic zones for Mexico.. A.J. Figueroa (University of Mexico) proposed three zones, after Mexico earthquake 1985, based on frequency of seismic activity. In a more recent study, the proposed seismic zones for Mexico changed to 4, zone A is a zone with no damage, zone D is the zone with major damage. In both studies, the coastal area affected by the Oaxaca and Guerrero earthquakes is identified as being the locus of the highest frequency of occurrence of the most severe earthquakes.

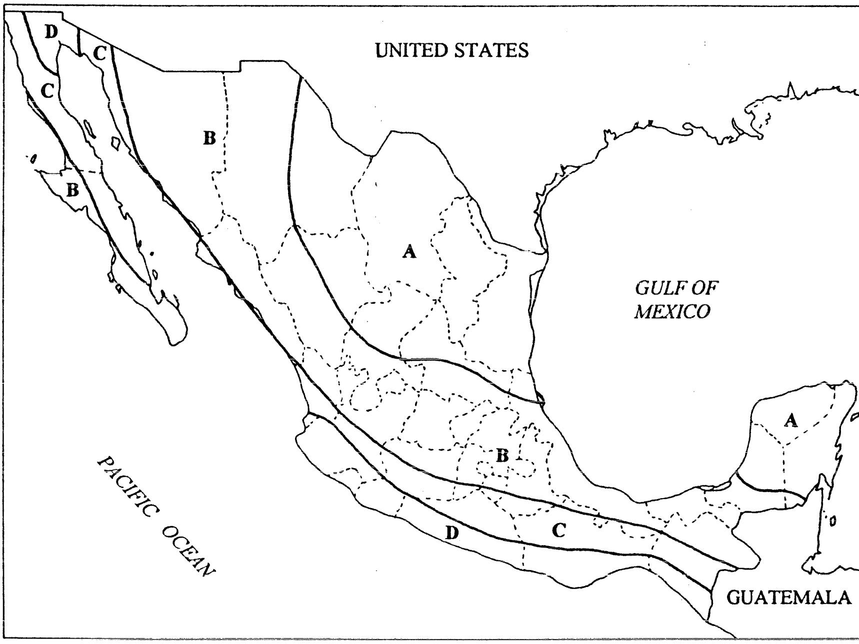

Figure 6 Seismic zone map of Mexico: Zone A - no damage; Zone B - minor damage; Zone C - moderate damage; Zone D - major damage.

The 500 km (300 mile) ribbon of Mexiçan Pacific coastline that stretches from Manzanillo, Colima to Acapulco, Guerrero has long been considered one of the world's beautiful places, home to sprinkling of fishing hamlets and resorts. Yet beneath the indigo waves and silky white beaches lies a jagged fault line that could be one of the deadliest in Western Hemisphere.

This coastline is composed of a dozen large plates and several smaller ones, ranging in thickness from 30 to 250 km (20 to 150 miles). The plates are in constant motion, riding on the molten mantle below and normally traveling at the pace of a millimeter a week, equivalent to the growth rate of a fingernail. The plate's travel results in continental drift, the formation of mountains, volcanoes and earthquakes.

When plates carrying two continental masses collide, the crust buckles creating craggy mountain ranges like the Himalayas. If they grind past each other, as the Pacific and North American Plates do under California's San Andreas Fault, friction locks them together. Every so often, abrupt slippages occur and the earth around them shudders in strike-slip quakes. Still another kind of tectonic phenomenon, the meeting of an oceanic and a continental plate, is responsible for the Mexican earthquakes.

With irresistible force, the Cocos plate, which forms part of the Pacific floor off Mexico, is pushing northeastward at a rate of 5 to 12 cm (2 to 4½ inches) a year against the North American plate, which is creeping westward. As the Cocos plate dips under the continent crust, motion of the oceanic mass is halted by friction in certain places. But the force propelling Cocos forward remains unrelenting, building up strain in the rock of both plates. When the frictional forces are overcome, the struck section of the Cocos plate lurches forward generating the shock waves of a thrust quake.

In a kind of seismic party line, one earthquake may signal that another could occur; sites that lie between past gaps hit by recent tremors are the areas most likely to rupture next. Noting that earthquakes in the 20th century have periodically shaken surrounding regions, geologists knew that Mexico's Michoacan gap could not hold forever.

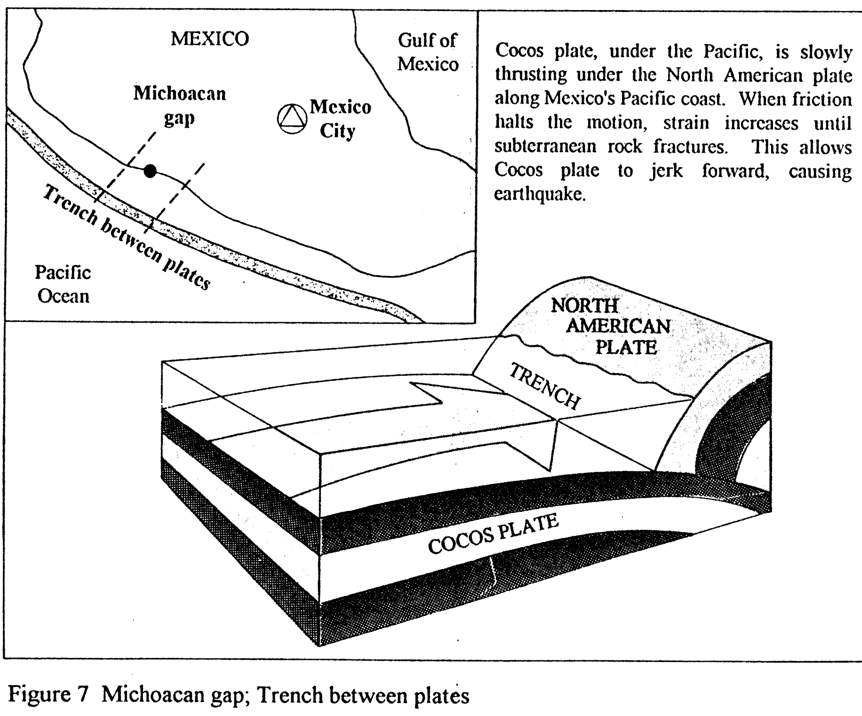

Figure 7 Michoacan gap; Trench between plates

CONCLUSION

The most important point to be made in any consideration of future earthquakes in North America is that fault activity will continue for countless centuries. And as long as there are fault movements, there will be earthquakes. Earthquakes are part of North America's heritage, and will remain a part of everyday life. The best way to overcome the damage associated with major seismic events is to analyze what has been done in an attempt to prepare for the future.

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