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Types of Hazards

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Chapter 4

Types of Hazards

In order to evaluate descriptions of events and the nature of the destruction described in 3rd Nephi, it is necessary to identify the nature of the various hazards potentially present, as well as the source of the hazard. All hazards described in 3rd Nephi can be accounted for as the products of volcanic eruption and regional earthquakes. It will also be useful to look at storm and hurricane hazards, as they may also have been operative.

Volcanic Hazards

The nature and product of volcanic eruptions has been discussed previously in chapter 3. The specific types of hazards and products from a volcanic eruption are:

1. Pyroclastic and surge flows
2. Volcanic debris slides
3. Lahars
4. Ash and tephra fall
5. Volcanic earthquakes
6. Tsunami
7. Lava flow

Pyroclastic and Surge Flows

Pyroclastic and surge flows are probably the most well known of all of the lethal volcanic events. The ancient eruption of Mount Vesuvius that destroyed Pompeii and Herculeum is probably the most famous. In a volcanic disaster of modern times, pyroclastic flows from the eruption of Mount Pelée on the island of Martinique in the Caribbean completely destroyed the capital city of St. Pierre within minutes of the eruption. There were only three survivors in the direct path of the volcano: Louis-Auguste Cyparis survived because he was in a poorly ventilated, dungeon-like jail cell; Leon Compere-Leandre, living on the edge of the city, escaped with severe burns; Havivra Da Ifrile, a young girl, escaped with only injuries by taking a small boat to a cave down shore during the eruption, and was later found adrift two miles from the island, unconscious.

Volcanic Debris Slides

The occurrence of the 1980 sector collapse and debris avalanche at Mount St. Helens triggered the recognition of uniquely hummocky deposits of many analogous debris avalanches at volcanoes worldwide (Vallance et al., 1995).

Figure 39. Destruction of city of Saint-Pierre by Mount Pelée in 1902, volcanic pyroclastic flow

Subsequent studies revealed the occurrence of edifice collapses and the flows transformed from them at several of the better-known volcanoes of the Trans-Mexican Volcanic Belt: Nevado de Colima and Volcánde Fuego volcanoes, Nevado de Toluca, Popocatépetl, Las Derrumbadas, and Pico de Orizaba (Capra et al., 2002).

A debris avalanche is a rapidly moving incoherent and unsorted mass of rock and soil mobilized by gravity (Schuster and Crandell, 1984). There are two types. The block type is composed mainly of debris avalanche blocks (an unconsolidated piece of the old mountain transported to its place of deposition) with practically no matrix. The mixed type is a mixture of rocks and matrix and may contain chunks of all rock types and of sizes from micrometers to meters.

In proximal areas the surface of a volcanic debris avalanche deposit generally consists of mounds (hummocks or volcanic hillocks) consisting of single debris avalanche blocks; in distal areas the surfaces are generally flat, with fewer mounds but with lateral levees and, in the cases of flows that did not transform to debris flows, an abrupt front. Mounds are the most distinguishing characteristic of volcanic debris avalanches and are the primary basis for recognition of several hundred large deposits of the flows around the world.

Figure 40. A thin, light-colored eruption plume rises above the summit of Mayon Volcano in the Philippines on September 14, 1984. The thicker column to the left is ash and gas roiling up from the surface of a pyroclastic flow moving down the southwest flank. (Smithsonian Global Volcanism Program, 2014)

Sector collapses are large volcanic landslides that remove the summit of the failed volcano, leaving an open, horseshoe-shaped crater (see figure 80), and generally have a volume in excess of 1 km^3, in some cases as much as several tens of km^3. Flank collapses are smaller failures that do not include the volcano summit.

The instability of a volcanic edifice is promoted by many factors directly related to volcanic activity as well as external processes such as weathering. These factors include direct magmatic intrusion into the edifice or subvolcanic crust, deposition of voluminous pyroclastic deposits on steep slopes, hydromagmatic processes, and phreatomagmatic activity.

Progressive weakening of a volcanic edifice by hydrothermal alteration is the fundamental indirect factor leading to collapse. The tectonic setting of the volcano may influence the direction of collapse (Siebert, 1984), and in some cases faulting may trigger collapse (McGuire, 1996). Although simple gravitational failure may occur in response to progressive weakening of an edifice, discrete triggering mechanisms are commonly independent of the processes producing edifice instability. Keefer (1984) established that numerous large landslides during historic time were triggered by earthquakes. Schuster and Crandell (1984) determined that approximately 35% of landslides causing natural dams were caused by earthquakes.

Lahars

One of the more unusual products of volcanoes is a lahar, or mudflow, that can occur at the time of the eruption (primary lahar) or for years afterwards (secondary lahar). In the 3rd Nephi account, the description accommodates the possibility of primary lahars that occurred at the time of the initial eruption or within 3 days afterwards.

Primary lahars can be generated by pyroclastic flows or by eruptions of crater lakes, water saturated volcanoes or snow topped volcanoes (such as Pico de Orizaba). A pyroclastic flow can easily entrain water from streams and rivers as it moves down topographic lows. In the process, the gas-rich flow is slowly converted to a fast moving, heated mudflow as more water is entrained in the mix. The Toutle River lahars from Mount St. Helens in 1980 had this origin. Volcanoes with crater lakes can produce mudflows at the time of any eruption, if the crater lake is ruptured. The size of the mudflow is then related directly to the volume of water in the lake. The 1919 eruption of Mt. Kelat on Java expelled water from a crater lake, covering 200 km^2 of farmland and killing over 5000 people.

Secondary lahars are caused by rain falling on freshly deposited, uncompacted tephra. Such watersoaked material is very unstable, and can move downslope as a mudflow that entrains all loose debris in its path. Such flows have covered enormous areas. The eruption of Mount Pinatubo in 1991 in the Philippines was one of the largest of the twentieth century. On the day of the climactic eruption, Typhoon Yunya passed close to the volcano. First its winds scattered tephra to a thickness of 10–33 cm over an area of 2000 km^2, second its rain soaked into the ash and caused many buildings to collapse, and third, runoff turned the pyroclastic flows into enormous lahars. A typical lahar was 2–3 m deep and 20–50 m wide. It consisted of 50 per cent ash moving as slurry at velocities of 4–8 meters per second (9–17 mph). A few lahars reached speeds of 11 meters per second (25 mph). Lahars can extend far beyond the range of the pyroclastic event, as they flow in channels just like rivers. They are not easily outrun at the speeds they can reach.

Ash and Tephra Fall

The eruption of Vesuvius in 1944 illustrates another major hazard of volcanic eruptions. At that time the Allied war effort in the area was severely hampered by the bombing of airfields, not by the Germans, but by liquid lava blobs tossed out by the volcano.

Virtually all explosive volcanic eruptions shoot ash upwards as high as 30 kilometers. Larger projectiles are launched by the volcanic eruption and can fall as far as 5 km away. The larger particles consist of boulder-sized blobs of fluid magma and remnant blocks of the volcano walls. This type of debris can be voluminous and hot, and can fall over a small area. It can also be extremely destructive and deadly. While ash falls are typically not a cause of direct mortality, the deposition of the large quantities of ash, especially when wet, can cause collapse of the roofs of buildings.

Figure 41. Lahar deposits produced by redistribution of material shed off the Santiaguito lava dome, visible below the steam plume to the left of Guatemala's Santa María volcano, have had dramatic effects on downstream drainages. This December 1988 photo shows the Río Tambor, southwest of Santa María, filled bank-to-bank with debris. Bridges such as the one in the foreground have been frequently destroyed during rainy-season lahars, which have traveled 35 km or more from the volcano. (Smithsonian, 2014)

Volcanic Earthquakes

The nature of volcanic earthquakes is discussed in detail in chapter 6. Generally speaking, the intensity of volcanic earthquakes is only strong enough to cause significant damage within a few tens of kilometers from the volcano.

Tsunami

Tsunami (both the singular and plural forms of the word are the same) are water wave phenomena generated by the shock waves associated with seismic activity, explosive volcanism, or submarine landslides. These shock waves can be transmitted through oceans, lakes, or reservoirs.

A tsunami can have a volcanic origin. Of the potential sources of tsunami generated by volcanoes, 16.5% resulted from tectonic earthquakes associated with the eruption, 20% from pyroclastic (ash) flows or surges hitting the ocean, and 14% from submarine eruptions. Only 7% resulted from the collapse of the volcano and subsequent caldera formation. Landslides or avalanches of cold rock accounted for 5%; avalanches of hot material, 4.5%; lahars (mud flows), 3%; atmospheric shock waves, 3%; and lava avalanching into the sea, 1%. About 25% had no discernible origin, but probably were produced by submerged volcanic eruptions (Bryant, 2005).

In the case of the Isthmus of Tehuantepec, the only volcano that is adjacent to the Gulf of Mexico is the San Martín volcano, and the only potential tsunami source from it are volcanic earthquakes, pyroclastic flow, lahar, landslide/debris flow of cold or hot material, atmospheric shock wave, or lava reaching the ocean. However, tsunami generated close to shore are not as large as those generated in deeper water, a factor to consider when evaluating potential tsunami implications in an evaluation of a 3rd Nephi scenario.

Lava Flows

While often the most visually spectacular of volcanic hazards, lava flows are principally a hazard to property, instead of a primary risk to human life. Inhabitants typically have sufficient notice of the arrival of lava from a volcano so that they are able to escape if escape routes are available. The average speed of a lava flow is 30 km per hour (18 mph), so lava flows can be outrun or be seen with enough notice to evade. They also follow topography and can be avoided by seeking higher ground. However, if the population has established itself on the volcano itself or is on or immediately adjacent to the eruption, than there can be significant loss of life, especially in the event of an eruption that occurs on the flank of the volcano.

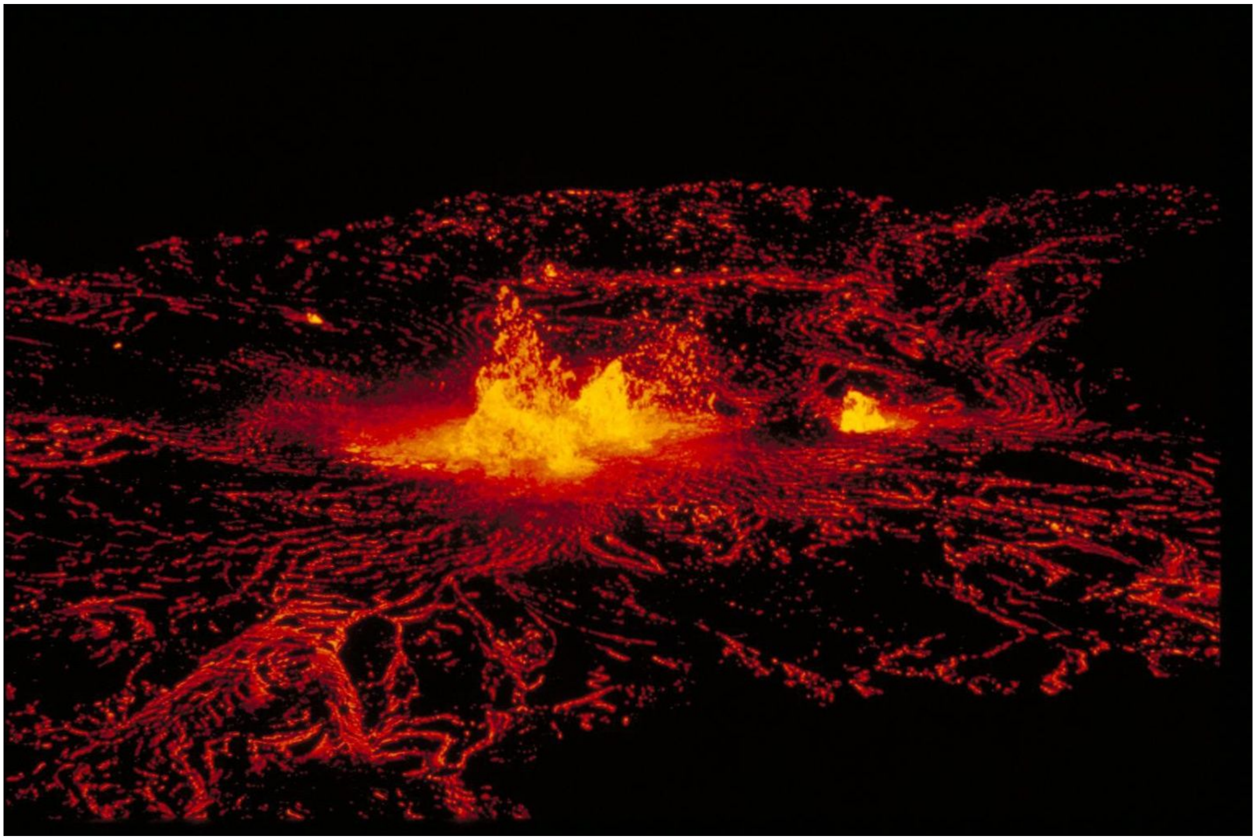


Figure 42. Lava at Hawaii Volcanoes National Park (courtesy US National Parks Service, 2014)

Earthquake Hazards

Strike-Slip Fault Surface Subsidence, Surface Fracture and Rupture

While it is common knowledge that a simple type of fault causes one side of the earth to go down and the other up (normal fault), there are a whole myriad of fracture and rupture patterns that are unique to a strike-slip fault. The Veracruz fault zone has its share of normal faults as well, but the dominant faults are the strike-slip faults.

In discussing this area of inquiry, it is useful to keep in mind the 3rd Nephi description of what happened to the earth, particularly in the land northward:

> And behold, the rocks were rent in twain; [yea] they were broken up upon the face of the whole earth, insomuch that they were found in broken fragments, and in seams and in cracks, upon all the face of the land. 3 Nephi 8:18

As the principal type of fault involved in this analysis is a strike-slip fault, hazards related to this type of fault need to be evaluated. Because slip is horizontal and parallel to a straight fault line, a perfectly planar strike-slip fault causes neither extension nor shortening; consequently there is no associated topography. However, long strike-slip faults do not occur as one plane and follow a staircase-like trajectory made up of alternating long and a straight fault lines connected by oblique bends or jogs.

Strike-slip faults are commonly segmented, typically in echelon pattern separated by offsets (or step-overs). These step-over zones of host rock between the end and the beginning of two adjoining shear fractures deform in order to accommodate continued strike-slip displacement. This local deformation may lead to the formation of short fault segments that connect adjacent echelon fault segments and result in a through-going fault zone. The geometry of these step-over zones and linking faults, in turn, controls contractional or extensional deformation according to the sense of slip and stepping direction of the echelon fault segments.

Figure 43 shows the stepped fault or echelon pattern, the first part of the diagram demonstrates what happens between the fault steps, showing areas of extension (where the earth is being pulled apart) and areas of contraction (where the earth is under pressure). The second part of the diagram shows the same thing, except in the situation where the echelon fault system has linked into one fault. The third part of the diagram shows area where the earth will drop or subside (pull-apart) and areas where the earth will rise or uplift (push-up).

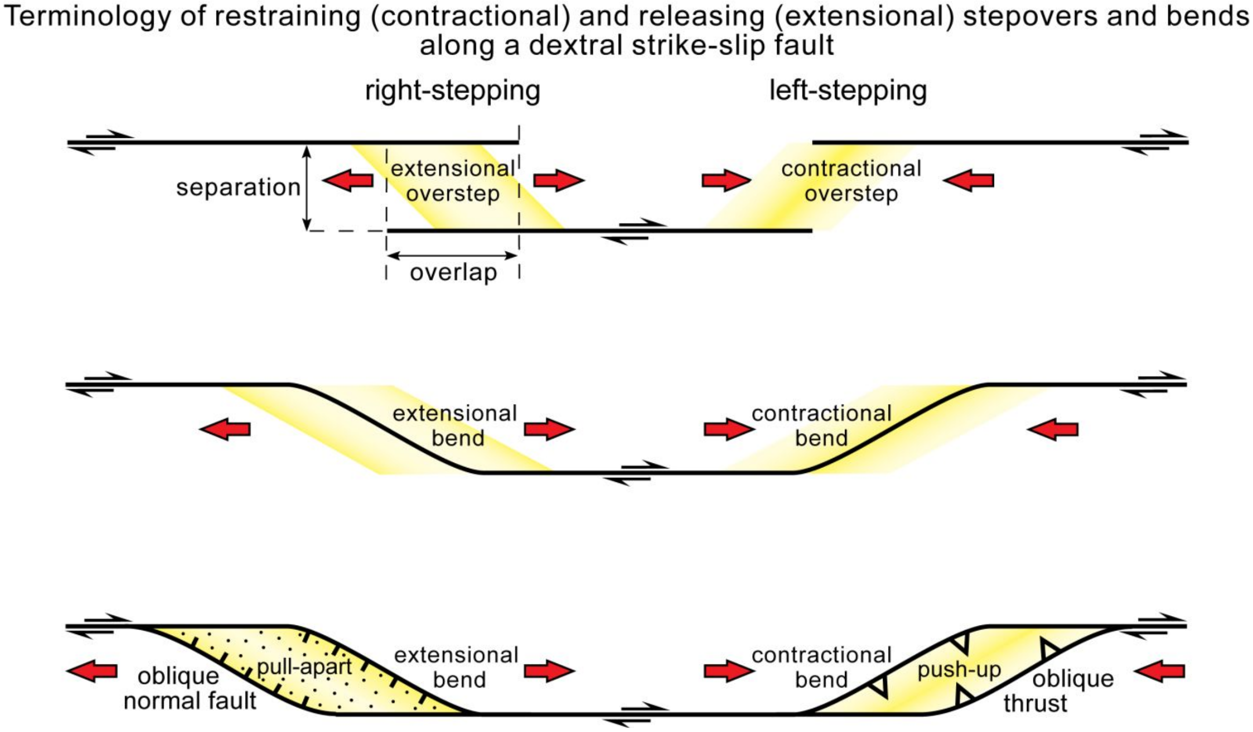


Figure 43. Diagram of subsidence and uplift zones along a strike-slip fault system (Berg, 2013)

The larger fault systems, (such as the Veracruz fault system) are more complex between the connections of the different fault planes. Figure 44 shows the multiple extensional (pull apart) and contractional (pushing together) zones that form complex ruptures and fractures combined with subsidence and uplift.

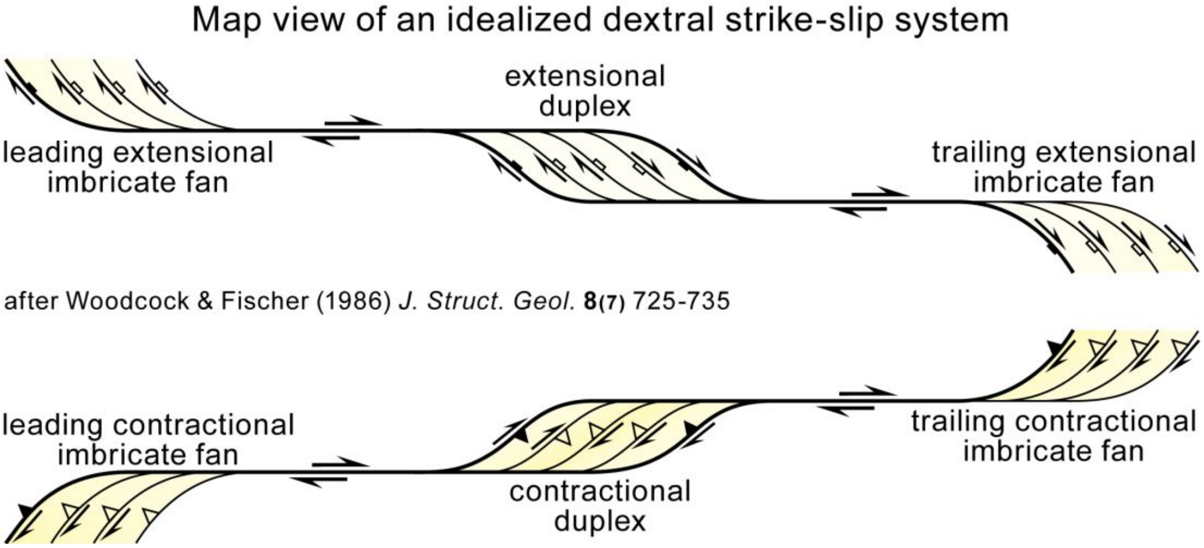


Figure 44. Complex fracture and rupture patterns in areas of subsidence and uplift in strike-slip fault system (Berg, 2013)

A strike-slip fault system also commonly shows a complex braided pattern of anastomosing contemporaneous faults reflected in surface rupture and fracture. Contractional and extensional bends and offsets can thus alternate along a single yet complex strike-slip zone (figure 45).

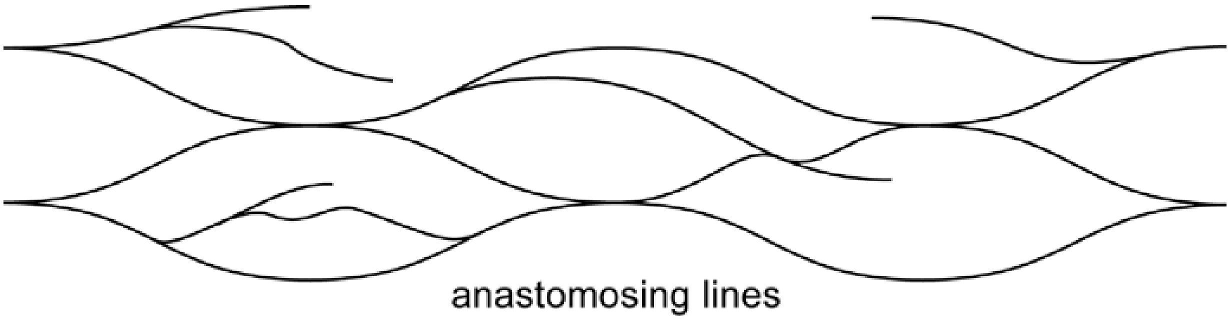


Figure 45. Braided pattern on strike-slip fault (Berg, 2013)

At the ends of the different sections of a particular fault in a strike-slip fault system, if it doesn't connect to another fault, a "horsetail" splay pattern of surface rupture typically occurs (see figure 46).

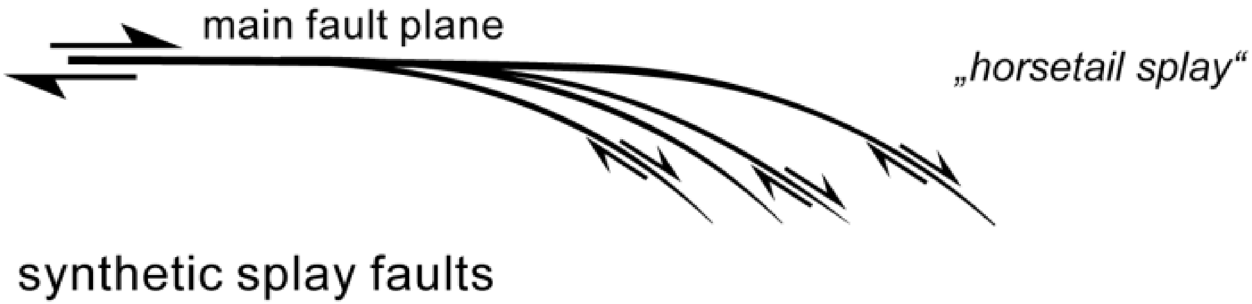
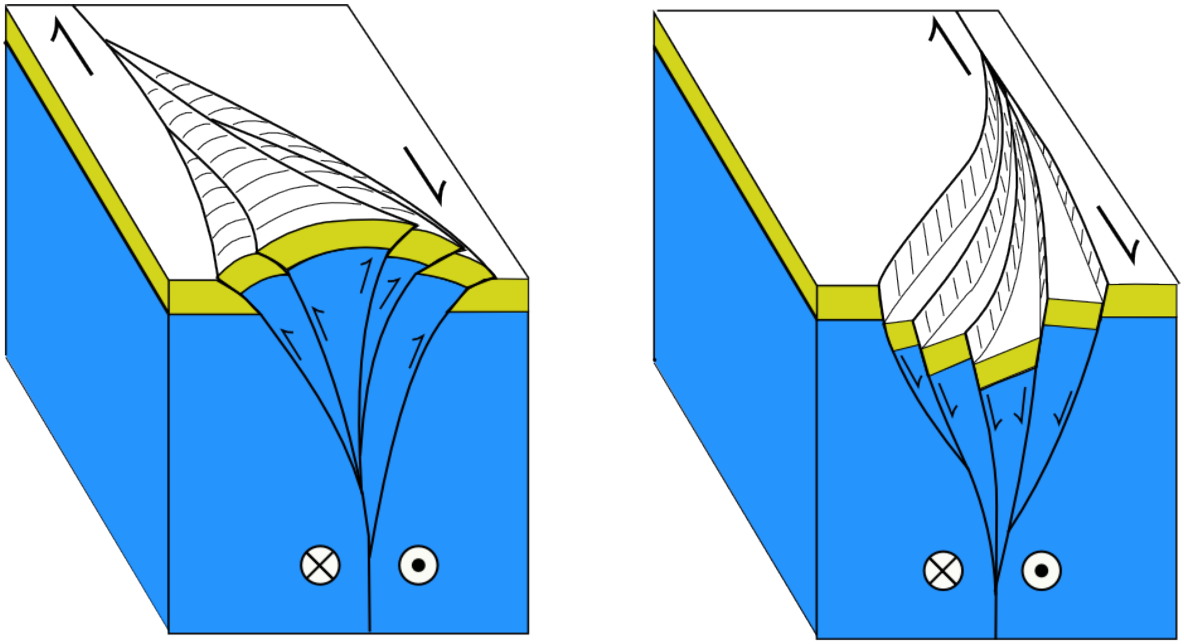


Figure 46. Splay fault and rupture pattern at the end of a strike-slip fault (Berg, 2013)

In areas of a strike-slip fault where the fault bends or where one fault plane connects to another fault plane subsidence and uplift structures are formed called "flower structures" (see figure 47).



Positive Flower

Negative Flower

Figure 47. Flower structures of a strike-slip fault (courtesy Creative Commons, 2014)

Rotational movements also occur along strike-slip faults that cause subsidence and uplift (see figure 48).

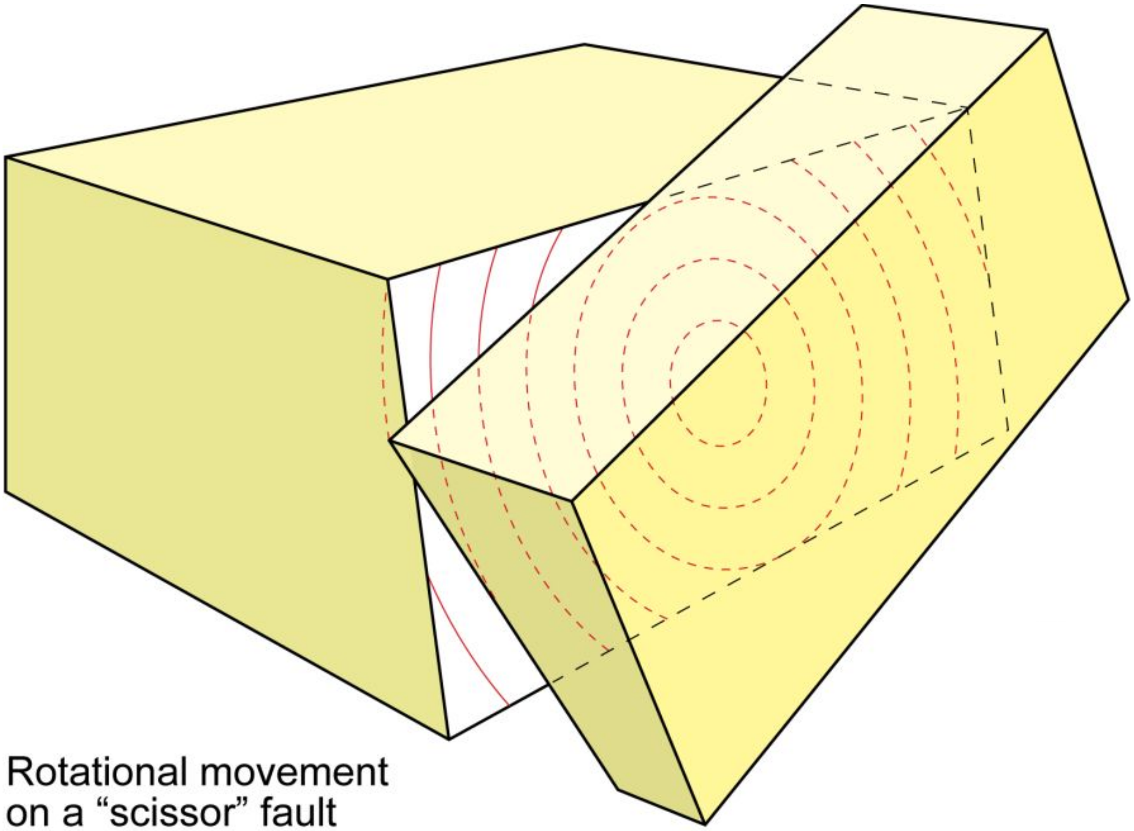


Figure 48. Strike-slip scissor fault movement (Berg, 2013)

In addition to the surface rupture and subsidence patterns above, shear faults nearly perpendicular to the fault line also form (see figure 49).

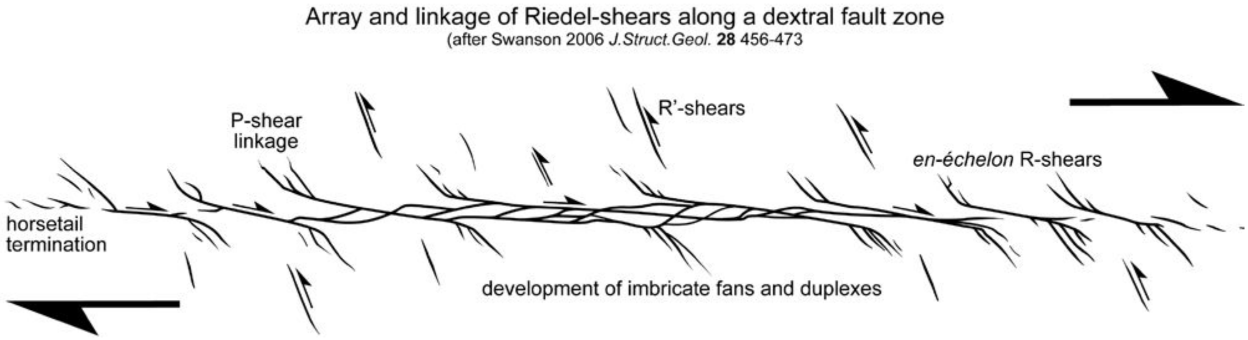


Figure 49. Typical shear faults along main strike-slip fault zone (Berg, 2013)

In rock types that aren't brittle, instead of fractures, folds can form that also create uplift and subsidence (see figures 50 and 51).

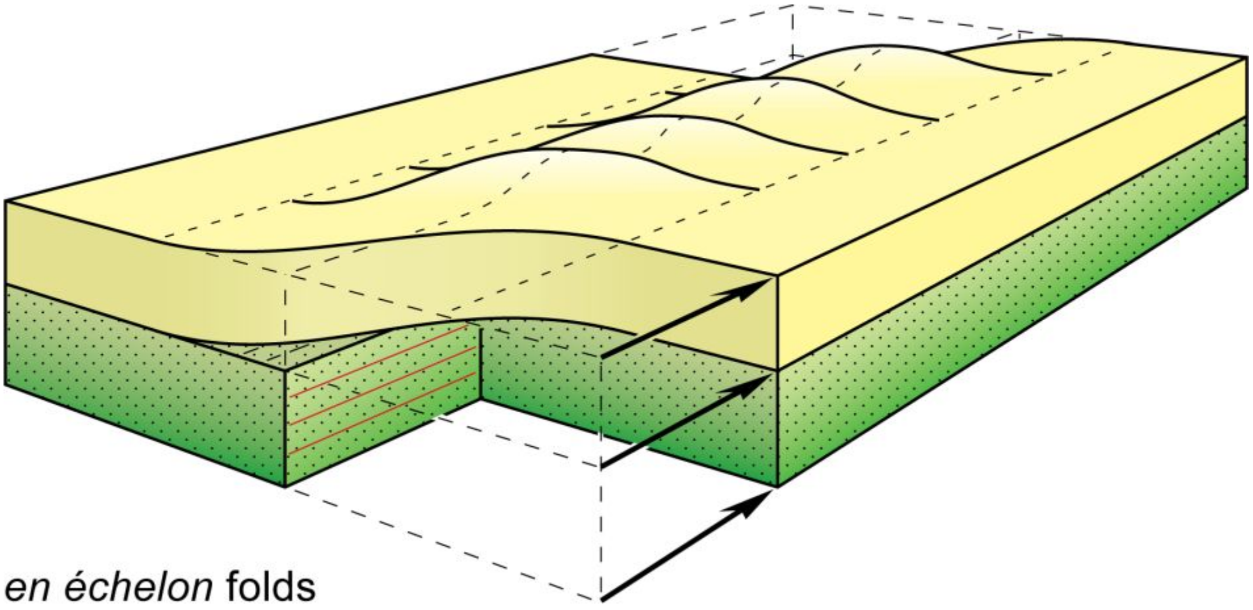


Figure 50. Strike-slip fault folding (Berg, 2013)

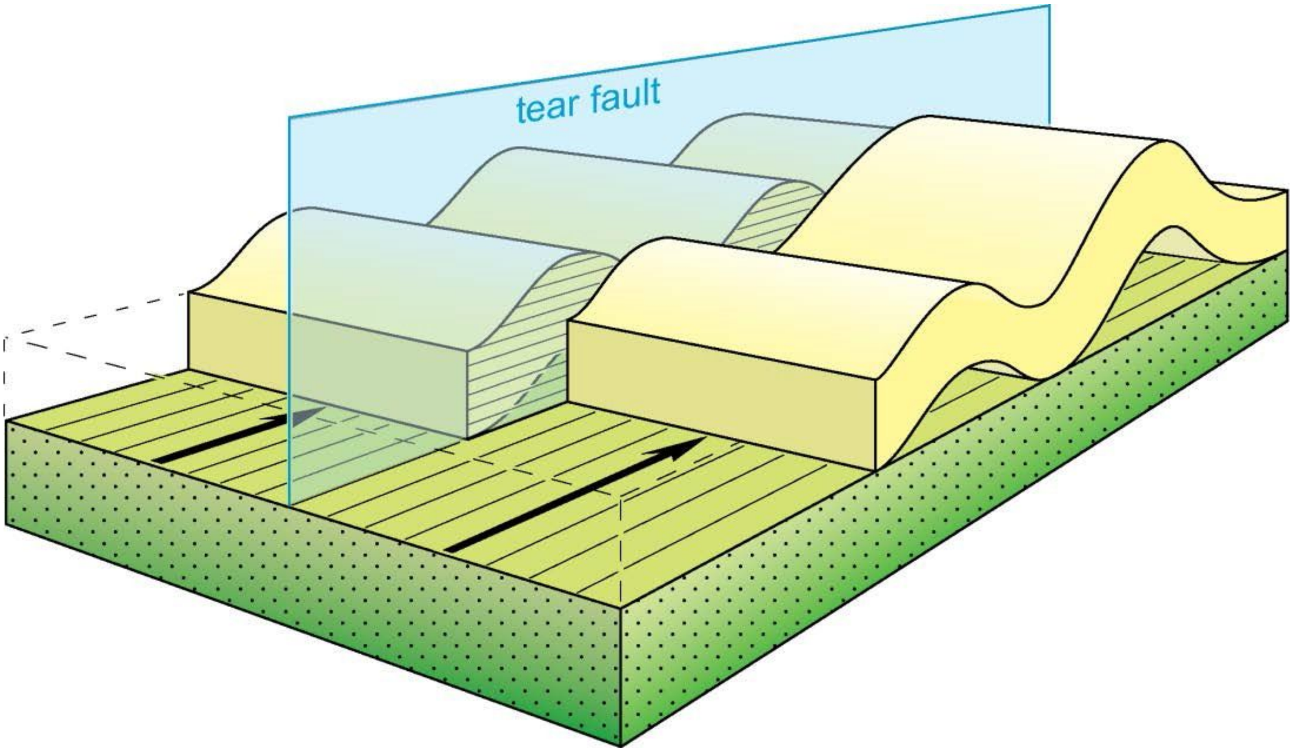


Figure 51. Strike-slip tear fault folding (Berg, 2013)

As can be seen, the surface fracture and rupture patterns from a strike-slip fault system can be widespread, extensive, and complex.

Ground shaking

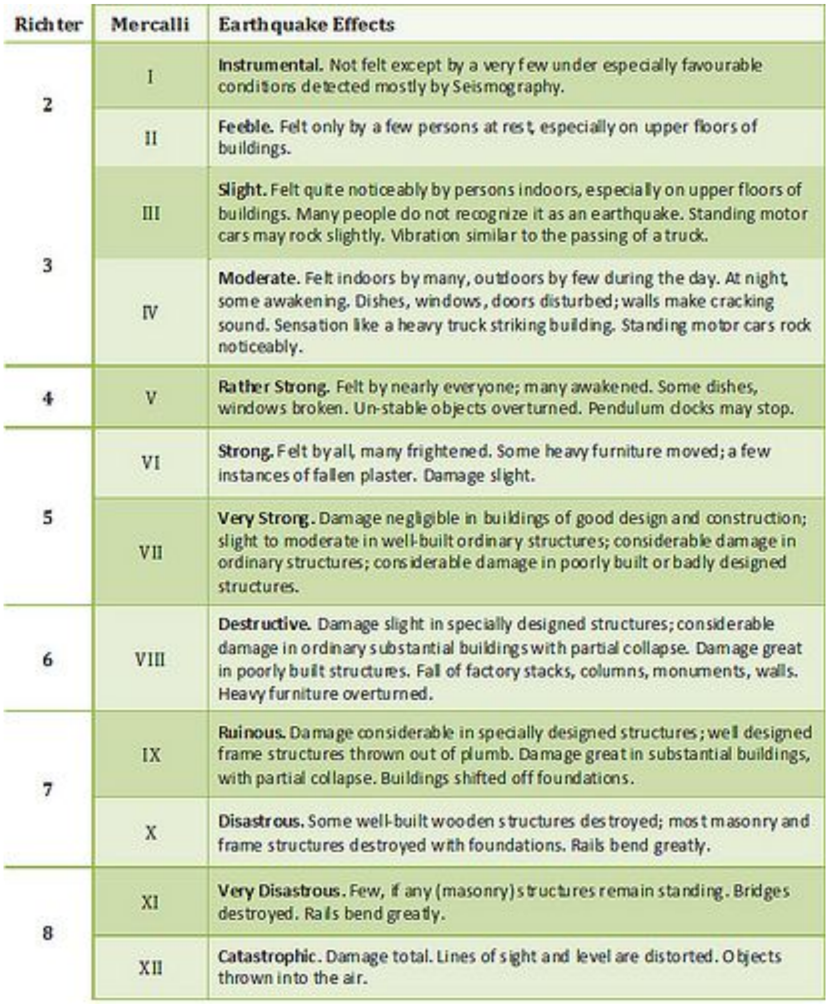
The effects of an earthquake are strongest in a broad zone surrounding the epicenter. The extent of earthquake vibration and subsequent damage to a region is partly dependent on characteristics of the ground. For example, earthquake vibrations last longer and are of greater wave amplitudes in unconsolidated surface material, such as poorly compacted fill or river deposits; bedrock areas receive fewer effects. The worst damage occurs in densely populated urban areas where structures are not built to withstand intense shaking.

Damage and loss of life sustained during an earthquake result from falling structures and flying glass and objects. Flexible structures built on bedrock are generally more resistant to earthquake damage than rigid structures built on loose soil.

Earthquake magnitudes are typically represented using the Moment Magnitude scale, which is essentially identical to the formerly used Richter Scale for moderate to large size earthquakes, but the Richter Scale was not effective for extremely large earthquakes, so the Moment Magnitude scale was developed. The Richter Scale is based on the measurement of ground shaking by seismic measurement devices. The Moment Magnitude scale was introduced by Hiroo Kanamori and Thomas Hanks in 1979. It is used by seismologists, geologists, and scientists. They use it to compare the size of earthquakes where the Richter scale is not so accurate. The Moment Magnitude Scale is more precise. It is not based on instrumental recordings of an earthquake but is based on the area of the fault that moved at the same moment as an earthquake. Magnitude scales differ from earthquake intensity scales, intensity is the perceptible shaking and local damage experienced during a quake.

Earthquake intensities, as opposed to magnitudes, are measured using the Mercalli scale, which can be used to compare historical earthquakes, where damage descriptions can help estimate the shaking intensity. The shaking intensity at a given spot depends on many factors, such as soil types, soil sub layers, depth, type of displacement, and range from the epicenter (not counting the complications of building engineering and architectural factors). Rather, magnitude scales are used to estimate with one number the size of the quake. Table 1 shows a comparison between the Richter magnitude scale and the Mercalli intensity scale. The Mercalli scale is also referred to as the Modified Mercalli scale, both terms are used in the book because some reference formulas and derivations use the Modified Mercalli term. Also, the formal Mercalli scale is designated in Roman numerals. However, in this book both the Roman numerals will be used and their equivalent standard numerals when using the Mercalli scale. The use of standard numerals for the Mercalli scale is needed for calculations, derivation, and graphical/map representations.

Table 1. Richter vs. Mercalli scales



Richter	Mercalli	Earthquake Effects
2	I	**Instrumental.** Not felt except by a very few under especially favourable conditions detected mostly by Seismography.
	II	**Feeble.** Felt only by a few persons at rest, especially on upper floors of buildings.
3	III	**Slight.** Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck.
	IV	**Moderate.** Felt indoors by many, outdoors by few during the day. At night, some awakening. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like a heavy truck striking building. Standing motor cars rock noticeably.
4	V	**Rather Strong.** Felt by nearly everyone; many awakened. Some dishes, windows broken. Un-stable objects overturned. Pendulum clocks may stop.
5	VI	**Strong.** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	VII	**Very Strong.** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in ordinary structures; considerable damage in poorly built or badly designed structures.
6	VIII	**Destructive.** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of factory stacks, columns, monuments, walls. Heavy furniture overturned.
7	IX	**Ruinous.** Damage considerable in specially designed structures; well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
	X	**Disastrous.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bend greatly.
8	XI	**Very Disastrous.** Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bend greatly.
	XII	**Catastrophic.** Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Liquefaction

Liquefaction is a process that occurs when saturated fine sands and silts temporarily lose strength and behave like a fluid during strong earthquake shaking (generally VII or greater). Such soils may be up to 10 m below the ground surface. Liquefaction effects can include sand boils or sand volcanoes (ejections of sand and water from a central point) and lateral spreading (ground fissuring, spreading settlements, accompanied by sand and water ejections), especially adjacent to rivers and streams or along roads, embankments, and reclaimed areas in low-lying alluvial and coastal areas. Sand boils in alluvium are often non-damaging, but lateral spreading can result in severe ground damage, causing buildings to tilt or deform, buried tanks and pipes to float, disrupting underground services and deforming and closing roads and railway lines.

Figure 52. Lateral spreading caused by October 2013, 7.1 magnitude earthquake in Bonol, Philippines (courtesy AFP News, 2013; LDE, Ltd., 2014)

Figure 53. 1964 7.5 magnitude earthquake tilting of apartment buildings at Kawagishi-Cho, Niigata, from liquefaction (courtesy National Academies of Science, 2014)

Figure 54. Liquefaction sand ejectment from 2011 6.1 magnitude earthquake, Christchurch, New Zealand

Tsunami

Submarine earthquakes are the primary cause of tsunami. The displacement of the Earth's crust by several meters during underwater earthquakes may cover tens of thousands of square kilometers and impart tremendous potential energy to the overlying water. Submarine earthquakes have the potential to generate landslides along the steep continental slope that flanks most coastlines. In addition, steep slopes exist on the sides of ocean trenches and around the thousands of ocean volcanoes, seamounts, and atolls on the seabed.

Landslides

Landslide is a general term for gravitational movements of rock or soil down a slope, the term 'soil' includes both 'earth' (material smaller than 2 mm) and 'debris' (material larger than 2 mm); 'rock' is a hard intact mass in its natural place before slope failure movement. Landslides can occur spontaneously, but are most often triggered by heavy rainfall or by earthquakes. Generally speaking, shaking on the Mercalli scale at intensity level VII (7) can cause small landslides (less than a thousand cubic meters), but an intensity level of VIII (8) is generally required for larger landslides (greater than a thousand cubic meters) (Hancox, 2005).

Small landslides of a few tens of cubic meters often do little damage, but very large failures of millions of cubic meters moving downslope can overrun and bury buildings, roads, and people.

Case Study: 1855 Wairarapa Earthquake

Since the primary fault system of interest in the Isthmus of Tehuantepec is the Veracruz strike-slip fault system, it would be useful to compare a more modern documented strike-slip earthquake that occurred with similar geography. The Wairarapa earthquake in New Zealand occurred on January 23, 1855, with a magnitude of 8.2. This earthquake was similar to what would be expected for a large Veracruz fault earthquake. The earthquake movement was along a 100 km section of the Wairarapa Fault. Land on one side of the fault moved north 13 meters to 20 meters and was uplifted or sunk as much as 6 meters. The earthquake caused landslides over a large area. River valleys and coastal plains experienced severe ground damage due to soil liquefaction in areas underlain by saturated alluvium and fine-grained sediments.

Earthquake shaking was felt over the whole country of New Zealand. Severe damage occurred throughout the southern half of the North Island. Mercalli intensities of 8 and 9 occurred in some areas. Ground damage in the form of fissuring, differential settlement, lateral spreading, liquefaction, and sand boils was severe in river valleys and coastal plains in the 8–9 intensity areas. Similar to the Veracruz fault, a portion of the Wairarapa Fault sits offshore running alongside the coast. The earthquake generated a tsunami that exceeded 10 meters in height. The earthquake also caused seismic seiching (sloshing caused by the passage of seismic waves) in many rivers, lakes, and harbors. Aftershocks to the main earthquake occurred on the main and on parallel faults, some in the 6 to 7 range in magnitude (Downes, 2005).

Storm and Hurricane Hazards

When a hurricane makes landfall, the shear force of hurricane-strength winds can destroy buildings, topple trees, bring down power lines, and blow vehicles off roads. In Book of Mormon times, the damage to buildings would have been worse as building construction techniques were more susceptible to high wind damage. When flying debris, such as roofing material, building siding, and small items left outside, is added to the mix, the potential for building damage is even greater. Threats to human safety from hurricane-force winds are equally severe. Many people have been killed or seriously injured by falling trees and flying debris. Individual storm clouds within hurricanes may spawn tornadoes as a hurricane makes landfall, with tornado production continuing, in some instances, for several days after landfall.

The coastal flooding triggered by hurricanes is as destructive as wind but can be even more deadly, and is by far the greatest threat to life and property along the coastline. Storm surge, wave, and tides are the greatest contributors to coastal flooding, while precipitation and river flow also contribute during some storms. Hurricane Katrina in 2005 is a prime example of the damage and devastation that can be caused by surge: at least 1600 fatalities stemmed from Katrina and many of those deaths occurred directly, or indirectly, as a result of storm surge.

Storm surge is the bulge of water that washes onshore during a storm, measured as the difference between the height of the storm tide and the predicted astronomical tide. It is driven by wind and the inverse barometric effect of low atmospheric pressure, and is influenced by waves, tides, and uneven bathymetric and topographic surfaces.

In addition to high winds and storm surge, hurricanes threaten coastal areas with their heavy rains. All tropical cyclones can produce widespread torrential rains, which cause massive flooding and trigger landslides and debris flows. Flash flooding can occur quickly due to intense rainfall over a relatively short period of time. Longer term flooding on rivers and streams can also persist for several days after a storm. Rain-triggered flooding is not just limited to coastlines as the reach of a large hurricane can cause deadly flooding well inland.

Table 2. Summary of 3rd Nephi Hazards and Events

As a useful reference, table 2 has been compiled indicating all the events, hazards, and damages identified in 3rd Nephi and related prophetic and descriptions contained in other parts of the Book of Mormon.

Hazard	**Reference (3rd Nephi)**	**Location**	**Characteristics**	**Time Frame**
Great storm	8:5		never had been known in all the land	arose approx. April 6
	8:19			lasted approx. 3 hours
Great and terrible tempest	8:6; 1 Nephi 19:11		associated with terrible thunder	
	8:19			lasted approx. 3 hours
	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
	Helaman 14:23		refers to more than one great tempest	**
Terrible thunder	8:6; 1 Nephi 19:11	whole earth	shook the whole earth as if to divide asunder	
	8:19			lasted approx. 3 hours
	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
	Helaman 14:21, 26			lasted space of many hours, **

Hazard	Reference (3rd Nephi)	Location	Characteristics	Time Frame
Exceeding sharp lightening	8:7; 1 Nephi 12:4; 1 Nephi 19:11		never had been known in all the land	
	8:19			lasted approx. 3 hours
	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
	Helaman 14:21, 26			lasted space of many hours, **
Earth carried up/covered with earth	8:10, 8:25, 9:5; 1 Nephi 19:11	Moronihah (implied land southward)	replaced by a great mountain, mountain carried up	
Whirlwinds	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
	8:16	land northward	persons carried away	
Great quaking of the whole earth	8:6	whole earth	whole earth was about to divide asunder	
	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
	8:14	many great cities, land northward	buildings had fallen, inhabitants slain, place left desolate (along with burning and sinking of cities)	
	1 Nephi 12:4		cities tumble to the earth because of quaking	
	Helaman 14:21	face of the whole earth	above and below the earth, solid or more part of solid earth broken up	
Land deformation	8:17	face of the whole earth		
(land northward)			because of tempests, thundering, lightening, and quaking of the earth	
Sinking and burial/covered with earth	8:14	many great cities in land northward	inhabitants slain, places left desolate	
	9:6	City of Gilgal	inhabitants buried in the depths of the earth	
Darkness; vapor of darkness; mists of darkness	8:20-22	all the face of the land	inhabitants could feel the vapor of darkness, no candles, torches, dry wood could be lit, no glimmer, moon, sun, or stars could be seen	
	8:23, 10:9; 1 Nephi 19:10–11; Helaman 14:20, 27			3 days, **
	1 Nephi 12:4	on the face of the land of promise		
Sinking and burial, with water coming up in the stead thereof	9:6-7	cities of Onihah, Mocum, Jerusalem	inhabitants covered	
	4th Nephi 1:9	all cities sunk and covered with water	water coverage was permanent	

Hazard	Reference (3rd Nephi)	Location	Characteristics	Time Frame
Sinking with hills and valleys in the places thereof	9:8	cities of Gadiandi, Gadiomnah, Jacob, Gimgimno	inhabitants buried in the depths of the earth	
Plains of the earth broken up	1 Nephi 12:4			
Mountains tumbling into pieces	1 Nephi 12:4			
Earth trembling	10:9			ended on 3rd day
Rocks rend	10:9; 1 Nephi 12:4; 1 Nephi 19:12			ended on 3rd day
Earth rent	1 Nephi 12:4; Helaman 14:22	face of the whole earth	found in seams, cracks, broken fragments, earth rent the rocks	**
Dreadful groanings	10:9; 1 Nephi 19:12			ended on 3rd day
Tumultuous noises	10:9			ended on 3rd day
	1 Nephi 12:4		all manner of tumultuous noises	
Earth cleaved together	10:9			ended on 3rd day
Fire and smoke	1 Nephi 19:11			
Opening of the earth	1 Nephi 19:11			
Mountains made low	Helaman 14:23		mountains made low "like unto a valley"	**
Valleys which shall become mountains	Helaman 14:23		whose height is great	**

Damage	Reference	Location	Characteristics	Time Frame
City "take fire"; "burned with fire"	8:8, 8:24, 9:3	Zarahemla (implied land southward)	fire	
City "burned with fire"; "fire sent down"	9:9–11, 7:12–14; 1 Nephi 12:4	great city Jacob-Ugath, cities of Laman, Josh, Gad, Kishcumen, land northward	caused to be burned with fire, send down fire to destroy them	
Sinking of city into the sea	8:9, 9:4	Moroni (mplied land southward)	"sunk in the depths of the sea"	
City covered with earth	8:10, 8:25, 9:5	Moronihah (implied land southward)	"earth carried up" great mountain in its place	
Great and terrible destruction	8:11	land southward		
More (higher level) great and terrible destruction	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
Face of the land changed	8:12	land northward	whole face of the land changed because of tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
Highways broken up	8:13; Helaman 14:24	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	**
Level roads spoiled	8:13	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
Many smooth places became rough	8:13	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth	
Many great and noble cities sunk	8:14; 1 Nephi 12:4	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth, inhabitants slain, place left desolate	
Many great and noble cities burned	8:14	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth, inhabitants slain, place left desolate	
Many great and noble cities shaken and buildings thereof fallen to the earth	8:14; 1 Nephi 12:4	land northward	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth, inhabitants slain, place left desolate	

Damage	**Reference**	**Location**	**Characteristics**	**Time Frame**
Remaining cities had great damage	8:15	land northward (implied the entire land northward)	as a result of the tempest, whirlwinds, thunderings, lightening, exceeding great quaking of the whole earth, inhabitants slain, place left desolate	
Face of the land deformed	8:17	face of the whole earth (in the land northward)	as a result of the tempest, thunderings, lightening, exceeding great quaking of the earth, inhabitants slain, place left desolate	
Rocks rent in twain, broken up, fragments, seams, cracks	8:18	face of the whole earth (in the land northward)	as a result of the tempest, thunderings, lightening, exceeding great quaking of the earth, inhabitants slain, place left desolate; found in broken fragments, and in seams and in cracks, upon all the face of the land	
Sinking cities with water coming up in the stead thereof	9:7	cities of Onihah, Mocum, Jerusalem	inhabitants covered	
Sinking cities with hills and valleys in the places thereof	9:8	cities of Gadiandi, Gadiomnah, Jacob, Gimgimno	inhabitants buried in the depths of the earth	
Cities shall become desolate	Helaman 14:24			**

** Helaman 14:27 states that all of the destructive items mentioned in Helaman would happen while the thunder, lightning, and the tempest lasted, which was the "space of many hours," with the exception of the darkness, which was the “space of three days.”