Geology of the Book of Mormon

Author(s): Jerry D. Grover, Jr.
Published: Vineyard, UT: n.p., 2014

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Jerry D. Grover, Jr., is a licensed Professional Structural and Civil Engineer and a licensed Professional Geologist. He has an undergraduate degree in Geological Engineering from BYU and a Master's Degree in Civil Engineering from the University of Utah. He has explored and mapped volcanic formations, precious metal deposits, and oil shale and gilsonite solid hydrocarbon deposits. In addition to providing geotechnical and civil engineering design for many private and public works projects, he has had managerial responsibilities over the Iron Springs iron deposits and has been a joint venture partner with Newmont Gold for a precious metal deposit near Cedar City, Utah. He took a 12-year hiatus from the sciences and served as a Utah County Commissioner from 1995 to 2007. He is currently employed as the site engineer for the remediation and redevelopment of the 1750-acre Geneva Steel site in Vineyard, Utah

ISBN 978-0-9863189-0-0

On the front cover: in the upper row, the two middle images are details from the 14th century Codex Vindobonensis C, p. 38, showing the Popocatépetl Volcano (www.famsi.org); and the outer two images are details from the AD 1570 Codex Vaticanos Rios, pp. 138–39 (www.famsi.org). The lower image is of the eruption of the Cordón Caulle Volcano in central Chile in 2011 (used with permission from Reuters).

On the back cover: two details from Codex Telleriano Remensis, AD 1563, pp. 42r and 42v. (www.famsi.org).

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Introduction

My first breath of life was taken on the extinct volcano Koʻolau. As a young missionary in Sicily I sat up late at night fascinated by the bright red incandescent lava streams moving down the slopes of Mount Etna, hearing the booms of dynamite detonated by desperate Italian geologists and engineers who were trying to divert the lava coming off the volcano to keep it from destroying homes and buildings. As a young man, I spent months traipsing through the deserts of Nevada mapping and drilling ancient volcanic deposits with the hopes of detecting traces of gold deposited in or beneath the volcanic deposits, and, shockingly, I actually found some. Without a lick of sense, I tried to see if I could keep my motorcycle upright while riding through the hurricane winds of Typhoon Alex on the streets of Taipei, Taiwan. My brief experience with natural hazards pales in comparison to the events described in 3rd Nephi in the Book of Mormon, but it has given me a great appreciation for the incredible power of nature that was put into motion two millennia ago.

For the last 30-plus years I have followed and studied with great interest the continuing development of serious studies of the Book of Mormon that try to figure out where Book of Mormon events actually took place. Over the years I have scooped up the various research and pseudo-research books and articles about Book of Mormon geography and culture. I have enjoyed digesting the recently released *Mormon's Codex* by Dr. John L. Sorenson and other books and articles on the topic. I have long waited for an in-depth inquiry into the implications of geology as applied to the Book of Mormon setting, but other than one brief overview article by Dr. Bart Kowallis from BYU (1997), it has not received much scientific scrutiny, nor has there been much attempt to actually look at the potential geologic locations in Mesoamerica. Do my history and qualifications as a professional geologist and a professional civil engineer mean I have any insight to offer Book of Mormon studies in this regard? The topic probably warrants a team of scientific experts analyzing the issue, but for the time being, I suppose I am as qualified as anyone to prepare a preliminary analysis of the issue.

This inquiry will look at the area of the Isthmus of Tehuantepec, which for the purposes of this book will include the areas from Mexico City to the Guatemala/Honduras border. I recognize that these are not the generally accepted boundaries of the Isthmus, but I take that approach in this book for ease of reference.

The geology of the Isthmus is both a geologist's paradise and a geologist's nightmare. A paradise because there is complex geology involving everything from volcanoes to earthquakes to subduction zones to petroleum provinces. A nightmare because interfingering, overlapping volcanic deposits are difficult to identify and map. It is also a nightmare because of the subtropical climate and vegetation that tends to obscure the visual geology of formations and fault lines and erode away much of the historic volcanic geology. The first caveat with regards to this book is that it is only as good as the data upon which it relies, which in many instances has significant gaps. The second caveat is that there will be few premises that will approach the 'proven' level; many of the conclusions will involve plausibility and 'best-fit' analysis based on the available data.

This book does not set out to prove the veracity of the Book of Mormon. The Book of Mormon stands by itself and it does not need self-proclaimed experts (or perhaps worse, non-proclaimed experts like myself) professing to have a smoking gun proving or disproving the Book of Mormon. This book also does not contain multiple chapters (as many other Book of Mormon geography books do) citing endless past statements of LDS General Authorities and other LDS Church leaders as to whether any prophets knew or did not know where any particular Book of Mormon location was. My guess is that if the LDS Church knew officially where a Book of Mormon location actually was, there would no doubt already be an LDS visitors' center located there.

Finally, this book does not discuss what Joseph Smith knew or didn't know. I don't know whether or not Joseph Smith was a closet geologist way ahead of his time capable of coming up with descriptions of volcanic avalanche morphological features long before geologists recognized them after the 1980 Mount St. Helens eruption. I will leave that discussion to others, as this effort is a scientific inquiry not a theological one.

Though this is not a theological book, questions will always arise when scientific inquiries confront religious phenomena. This book explains and interprets the events and descriptions found in the Book of Mormon that have a geologic basis. This book is not an attempt to discredit the religiosity of Book of Mormon events. In the Book of Mormon itself, Jesus Christ says that he "caused" most of the events, which leaves plenty of room for the religious faithful and agnostic scientists alike, and also for the increasingly rare breed known as a religious scientist.

The first purpose of this book is to evaluate and analyze the text of the Book of Mormon itself to provide clues as to the nature and location of the disaster. The second purpose is to lay out basic Isthmus geology (and to a limited extent, meteorology) and compare the geology and natural hazards with the text of the Book of Mormon. Finally, this book will provide geographic parameters based on the underlying geology for the locations mentioned in 3rd Nephi and for some other geologic references in the Book of Mormon, and will also compare those parameters with what has become known as the "Sorenson model" of Book of Mormon geography. I will not engage in the cherry picking of various parts of the Book of Mormon to push various ideas and proposals. To be viable, the analysis must look at every word and reference in the Book of Mormon to the destruction, including prophetic references. It must address and identify all of the natural destructive methods mentioned, as well as each of the types of damage that occurred. Anything less would not forward our understanding of Book of Mormon geology.

Chapter 1

Relevant Passages from the Book of Mormon

The destruction that is described in 3rd Nephi is found principally in chapters 8 and 9; however there are other prophetic visions found elsewhere in the Book of Mormon that also describe the destruction. To complete a thorough analysis of the destruction, it will be necessary to address all of the descriptions contained in the text and to provide plausible explanations for all of them. In order to make reading easier, the relevant portions of the Book of Mormon text related to the destruction are cited here.

The text cited here has also been reviewed against the text of the Book of Mormon as represented in *The Book of Mormon: The Earliest Text* by Royal Skousen (2009). For twenty-one years, Skousen has researched the earliest extant sources pertaining to the translation and publication of the Book of Mormon and has published in *The Earliest Text* what he has determined, to the extent possible, to be the original English-language text of the book. Additional words are delineated by brackets, with word and phrase differences delineated by strikeouts, and with the language from the Skousen text enclosed in brackets. No modifications were made to the punctuation or syntax, although it is recognized that the original Book of Mormon as dictated lacked punctuation and verse breaks, so there may be some variability in interpretation based on different punctuation scenarios. This was done because there are some textual differences in a few descriptions of the events. A true review needs to attempt to address any additional items that arise because of any original language perturbations.

Additional recitations of scriptures in this book will similarly include the Skousen text.

Prophecies of the Destruction

Nephi's Vision

1 Nephi 12:1–3

1. And it came to pass that I beheld many generations pass away, after the manner of wars and contentions in the land; and I beheld many cities, yea, even that I did not number them.

2. And it came to pass that I saw a mist of darkness on the face of the land of promise; and I saw lightnings, and I heard thunderings, and earthquakes, and all manner of tumultuous noises; and I saw the earth ~~and the rocks, that they rent~~ [that it rent the rocks]; and I saw mountains tumbling into pieces; and I saw the plains of the earth, that they were broken up; and I saw many cities that they were sunk; and I saw many that they were ~~burned~~ [burnt] with fire; and I saw many that did tumble to the earth, because of the quaking thereof.

3. And it came to pass [that] after I saw these things, I saw the vapor of darkness, that it passed from off the face of the earth; and behold, I saw [the] multitudes who had not fallen because of the great and terrible judgments of the Lord.

Zenos's Prophecy Recited by Nephi

1 Nephi 19:10–12

10. And the God of our fathers, ~~who~~ [which] were led out of Egypt, out of bondage, and also were preserved in the wilderness by him, yea, the God of Abraham, and of Isaac, and the God of Jacob, yieldeth himself, according to the words of the angel, as a man, into the hands of wicked men, to be lifted up, according to the words of ~~Zenock~~ [Zenoch], and to be crucified, according to the words of Neum, and to be buried in a sepulchre, according to the words of Zenos, which he spake concerning the three days of darkness, which should be a sign given of his death unto ~~those~~ [them] who should inhabit the isles of the sea, more especially given unto ~~those~~ [them]who are of the house of Israel.

11. For thus spake the prophet: The Lord God surely shall visit all the house of Israel at that day, some with his voice, because of their righteousness, unto their great joy and salvation, and others with the thunderings and the lightnings of his power, by tempest, by fire, and by smoke, and vapor of darkness, and by the opening of the earth, and by mountains which shall be carried up.

12. And all these things must surely come, saith the prophet Zenos. And the rocks of the earth must rend; and because of the groanings of the earth, many of the kings of the isles of the sea shall be wrought upon by the Spirit of God, to exclaim: The God of nature suffers.

Samuel the Lamanite's Prophecy

Helaman 14:20–29

20. But behold, as I said unto you concerning another sign, a sign of his death, behold, in that day that he shall suffer death the sun shall be darkened and refuse to give his light unto you; and also the moon and the stars; and there shall be no light upon the face of this land, even from the time that he shall suffer death, for the space of three days, to the time that he shall rise again from the dead.

21. Yea, at the time that he shall yield up the ghost there shall be thunderings and lightnings for the space of many hours, and the earth shall shake and tremble; and the rocks which ~~are~~ [is] upon the face of ~~this~~ [the] earth, which ~~are~~ [is] both above the earth and beneath, which ye know at this time ~~are~~ [is] solid, or the more part of it is one solid mass, shall be broken up;

22. Yea, they shall be rent in twain, and shall ever after be found in seams and in cracks, and in broken fragments upon the face of the whole earth, yea, both above the earth and beneath.

23. And behold, there shall be great tempests, and there shall be many mountains laid low, like unto a valley, and there shall be many places which are now called valleys which shall become mountains, whose height [thereof] is great.

24. And many highways shall be broken up, and many cities shall become desolate.

25. And many graves shall be opened, and shall yield up many of their dead; and many saints shall appear unto many.

26. And behold, thus hath the angel spoken unto me; for he said unto me that there should be thunderings and lightnings for the space of many hours.

27. And he said unto me that while the thunder and the lightning lasted, and the tempest, that these things should be, and that darkness should cover the face of the whole earth for the space of three days.

28. And the angel said unto me that many shall see greater things than these, to the intent that they might believe that these signs and these wonders should come to pass upon all the face of this land, to the intent that there should be no cause for unbelief among the children of men—

29. And this to the intent that whosoever will believe might be saved, and that whosoever will not believe, a righteous judgment might come upon them; and also if they are condemned they bring upon themselves their own condemnation.

Descriptions at the Time of or Immediately after the Destruction

From the Record Kept by Nephi, Disciple of the Risen Christ

3 Nephi 8:1–25

1. And now it came to pass that according to our record, and we know our record to be true, for behold, it was a just man who did keep the record—for he truly did many miracles in the name of Jesus; and there was not any man ~~who~~ [which] could do a miracle in the name of Jesus save he were cleansed every whit from his iniquity—

2. And now it came to pass, if there was no mistake made by this man in the reckoning of our time, the thirty and third year had passed away;

3. And the people began to look with great earnestness for the sign which had been given by the prophet Samuel, the Lamanite, yea, for the time that there should be darkness for the space of three days over the face of the land.

4. And there began to be great doubtings and disputations among the people, notwithstanding so many signs had been given.

5. And it came to pass in the thirty and fourth year, in the first month, ~~on~~ [in] the fourth day of the month, there arose a great storm, such an one as never had been known in all the land.

6. And there was also a great and terrible tempest; and there was terrible thunder, insomuch that it did shake the whole earth as if it was about to divide asunder.

7. And there were ~~exceedingly~~ [exceeding] sharp lightnings, such as never had been known in all the land.

8. And the city of Zarahemla did take fire.

9. And the city of Moroni did sink into the depths of the sea, and the inhabitants thereof were drowned.

10. And the earth was carried up upon the city of Moronihah that in the place of the city ~~there~~ [thereof] became a great mountain.

11. And there was a great and terrible destruction in the land southward.

12. But behold, there was a more great and terrible destruction in the land northward; for behold, the whole face of the land was changed, because of the tempest and the whirlwinds and the thunderings and the lightnings, and the ~~exceedingly~~ [exceeding] great quaking of the whole earth;

13. And the highways were broken up, and the level roads were spoiled, and many smooth places became rough.

14. And many great and notable cities were sunk, and many were burned, and many were ~~shaken~~ [shook] till the buildings thereof had fallen to the earth, and the inhabitants thereof were slain, and the places were left desolate.

15. And there were some cities which remained; but the damage thereof was ~~exceedingly~~ [exceeding] great, and there were many of them who were slain.

16. And there were some who were carried away in the whirlwind; and whither they went no man knoweth, save they know that they were carried away.

17. And thus the face of the whole earth became deformed, because of the tempests, and the thunderings, and the lightnings, and the quaking of the earth.

18. 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.

19. And it came to pass that when the thunderings, and the lightnings, and the storm, and the tempest, and the quakings of the earth did cease—for behold, they did last for about the space of three hours; and it was said by some that the time was greater; nevertheless, all these great and terrible things were done in about the space of three hours--and then behold, there was darkness upon the face of the land.

20. And it came to pass that there was thick darkness upon ~~all the face of the land~~ [the face of all the land], insomuch that the inhabitants thereof ~~who~~ [which] had not fallen could feel the vapor of darkness;

21. And there could be no light, because of the darkness, neither candles, neither torches; neither could there be fire kindled with their fine and ~~exceedingly~~ [exceeding] dry wood, so that there could not be any light at all;

22. And there was not any light seen, neither fire, nor glimmer, neither the sun, nor the moon, nor the stars, for so great were the mists of darkness which were upon the face of the land.

23. And it came to pass that it did last for the space of three days that there was no light seen; and there was great mourning and howling and weeping among all the people continually; yea, great were the groanings of the people, because of the darkness and the great destruction which had come upon them.

24. And in one place they were heard to cry, saying: O that we had repented before this great and terrible day, and then would our brethren have been spared, and they would not have been burned in that great city Zarahemla.

25. And in another place they were heard to cry and mourn, saying: O that we had repented before this great and terrible day, and had not killed and stoned the prophets, and cast them out; then would our mothers and our fair daughters, and our children have been spared, and not have been buried up in that great city Moronihah. And thus were the howlings of the people great and terrible.

3 Nephi 9:1–12

1. And it came to pass that there was a voice heard among all the inhabitants of the earth, upon all the face of this land, crying:

2. ~~Wo, wo, wo~~ [Woe, woe, woe] unto this people; ~~wo~~ [woe]unto the inhabitants of the whole earth except they shall repent; for the devil laugheth, and his angels rejoice, because of the slain of the fair sons and daughters of my people; and it is because of their iniquity and abominations that they are fallen!

3. Behold, that great city Zarahemla have I burned with fire, and the inhabitants thereof.

4. And behold, that great city Moroni have I caused to be sunk in the depths of the sea, and the inhabitants thereof to be drowned.

5. And behold, that great city Moronihah have I covered with earth, and the inhabitants thereof, to hide their iniquities and their abominations from before my face, that the blood of the prophets and [of] the saints shall not come any more unto me against them.

6. And behold, the city of Gilgal have I caused to be sunk, and the inhabitants thereof to be buried up in the depths of the earth;

7. Yea, and the city of Onihah and the inhabitants thereof, and the city of Mocum and the inhabitants thereof, and the city of Jerusalem and the inhabitants thereof; and waters have I caused to come up in the stead thereof, to hide their wickedness and abominations from before my face, that the blood of the prophets and the saints shall not come up any more unto me against them.

8. And behold, the city of Gadiandi, and the city of Gadiomnah, and the city of Jacob, and the city of Gimgimno, all these have I caused to be sunk, and made hills and valleys in the places thereof; and the inhabitants thereof have I buried up in the depths of the earth, to hide their wickedness and abominations from before my face, that the blood of the prophets and the saints should not come up any more unto me against them.

9. And behold, that great city ~~Jacobugath~~ [Jacob-Ugath], which was inhabited by the people of king Jacob, have I caused to be burned with fire because of their sins and their wickedness, which was above all the wickedness of the whole earth, because of their secret murders and combinations; for it was they that did destroy the peace of my people and the government of the land; therefore I did cause them to be burned, to destroy them from before my face, that the blood of the prophets and the saints should not come up unto me any more against them.

10. And behold, the city of Laman, and the city of Josh, and the city of Gad, and the city of ~~Kishkumen~~ [Kishcumen], have I caused to be burned with fire, and the inhabitants thereof, because of their wickedness in casting out the prophets, and stoning ~~those~~ [them] ~~whom~~ [which] I did send to declare unto them concerning their wickedness and their abominations.

11. And because they did cast them all out, that there were none righteous among them, I did send down fire and destroy them, that their wickedness and abominations might be hid from before my face, that the blood of the prophets and the saints ~~whom~~ [which] I sent among them might not cry unto me from the ground against them.

12. And many great destructions have I caused to come upon this land, and upon this people, because of their wickedness and their abominations.

3 Nephi 10:1–14

1. And now behold, it came to pass that all the people of the land did hear these sayings, and did witness of it. And after these sayings there was silence in the land for the space of many hours;

2. For so great was the astonishment of the people that they did cease lamenting and howling for the loss of their kindred which had been slain; therefore there was silence in all the land for the space of many hours.

3. And it came to pass that there came a voice again unto the people, and all the people did hear, and did witness of it, saying:

4. O ye people of these great cities which have fallen, ~~who~~ [which] are [a] ~~descendants~~ [descendant] of Jacob, yea, ~~who~~ [which] are of the house of Israel, [O ye people of the house of Israel] how oft have I gathered you as a hen gathereth her chickens under her wings, and have nourished you.

5. And again, how oft would I have gathered you as a hen gathereth her chickens under her wings, yea, O ye people of the house of Israel, ~~who~~ [which] have fallen; yea, O ye people of the house of Israel, ye that dwell at Jerusalem, as ye that have fallen; yea, how oft would I have gathered you as a hen gathereth her chickens, and ye would not.

6. O ye house of Israel whom I have spared, how oft will I gather you as a hen gathereth her chickens under her wings, if ye will repent and return unto me with full purpose of heart.

7. But if not, O house of Israel, the places of your dwellings shall become desolate until the time of the fulfilling of the covenant to your fathers.

8. And now it came to pass that after the people had heard these words, behold, they began to weep and howl again because of the loss of their kindred and friends.

9. And it came to pass that thus did the three days pass away. And it was in the morning, and the darkness dispersed from off the face of the land, and the earth did cease to tremble, and the rocks did cease to rend, and the dreadful groanings did cease, and all the tumultuous noises did pass away.

10. And the earth did cleave together again, that it stood; and the mourning, and the weeping, and the wailing of the people ~~who~~ [which] were spared alive did cease; and their mourning was turned into joy, and their lamentations into the praise and thanksgiving unto the Lord Jesus Christ, their Redeemer.

11. And thus far were the scriptures fulfilled which had been spoken by the prophets.

12. And it was the more righteous part of the people who were saved, and it was they who received the prophets and stoned them not; and it was they who had not shed the blood of the saints, ~~who~~ [which] were spared--

13. And they were spared and were not sunk and buried up in the earth; and they were not drowned in the depths of the sea; and they were not burned by fire, neither were they fallen upon and crushed to death; and they were not carried away in the whirlwind; neither were they overpowered by the ~~vapor~~ [vapors] of smoke and of darkness.

14. And now, whoso readeth, let him understand; he that hath the scriptures, let him search them, and see and behold if all these deaths and destructions by fire, and by smoke, and by tempests, and by whirlwinds, and by the opening of the earth to receive them, and all these things ~~are~~ [is] not unto the fulfilling of the prophecies of many of the holy prophets.

3 Nephi 11:1–3

1. And now it came to pass that there were a great multitude gathered together, of the people of Nephi, round about the temple which was in the land Bountiful; and they were marveling and wondering one with another, and were ~~showing~~ [shewing] one to another the great and marvelous change which had taken place.

2. And they were also conversing about this Jesus Christ, of ~~whom~~ [which] the sign had been given concerning his death.

3. And it came to pass that while they were thus conversing one with another, they heard a voice as if it came out of heaven; and they cast their eyes round about, for they understood not the voice which they heard; and it was not a harsh voice, neither was it a loud voice; nevertheless, and notwithstanding it being a small voice it did pierce them that did hear to the center, insomuch that there ~~was~~ [were] no part of their frame that it did not cause to quake; yea, it did pierce them to the very soul, and did cause their hearts to burn.

From the Record Kept by Nephi’s Son Who Was Also Named Nephi

4 Nephi 1:6–9

6. And thus did the thirty and eighth year pass away, and also the thirty and ninth, and [the] forty and first, and the forty and second, yea, even until forty and nine years had passed away, and also the fifty and first, and the fifty and second; yea, and even until fifty and nine years had passed away.

7. And the Lord did prosper them exceedingly in the land; yea, insomuch that they did build cities again where
8. Yea, even that great city Zarahemla did they cause to be built again.

9. But there were many cities which had been sunk, and waters came up in the stead thereof; therefore these cities could not be renewed.

Chapter 2
The Sorenson Model

One of the principal purposes of creating this geologic analysis is to utilize it to determine if various existing Book of Mormon geographical models are consistent with the geologic inquiry. This inquiry looks exclusively at potential Book of Mormon lands based in Mesoamerica within the Isthmus of Tehuantepec. It is also limited to the geography that existed at the time of the 3rd Nephi catastrophe.

There are dozens of individuals who have proposed various models for geographical configurations of the Book of Mormon. There are few models that are developed with what would be considered to have professional academic verification. Dr. John L. Sorenson has made a life's work of creating a plausible geographical model for Book of Mormon locations and his seems an excellent model to use for a comparison with the geologic analysis. The geographical comparisons come from Dr. Sorenson's most recent book, *Mormon's Codex* (2013) and his prior books, namely *Mormon's Map* (2000) and an *Ancient American Setting for the Book of Mormon* (1985).

A summary of each location related to the catastrophe and a brief summary of Sorenson's model related to the location are shown below. Maps of the locations are shown in figures 1 thru 4. Maps that have been included are those that show the proposed locations for geographical areas and cities that are also mentioned as part of the 3rd Nephi description of the destruction. Figure 5 shows existing cities and known archeological sites.

Figure 1 – The Sorenson Model


Moroni
ders by
east sea
east or south
wilderness
Caribbean Sea
(Usumacinta River)
(Grijalva River)
river Sidon
dom
land
southward
Zarahemla
Gideon
Zarahemla
Judea
Cumeni
Zeezrom
Helam
Antiparah
narrow strip of wilderness
Nephi
Jerusalem
Mormon
Nephi

Figure 2 – Sorenson Model Geographical Correspondences

"Mormon's Map" shows the most plausible arrangement of Nephite and Lamanite geographical features based on all the information in the record of Mormon and his son $Moroni_2$. (Capitalization of names follows the practice of the published text of the Book of Mormon.)

LEGEND

1. waters of Ripliancum
2. limit of Nephite final retreat
3. Shiz's death; plates left
4. hill Shim
5. narrow pass or passage
6. Hagoth's shipbuilding site
7. $Moroni_1$'s camp
8. Nephites' refuge between the land Bountiful and the land of Zarahemla (see 3 Nephi 3:23, 25)
9. hill Onidah
10. hill Amnihu
11. hill Riplah
12. valley of Alma
13. dispersal point of the sons of $Mosiah_2$
14. waters of Mormon
15. hill north of Shilom
16. mount Antipas
17. place Onidah
18. wilderness on the west of the land Zarahemla
19. wilderness on the west in the land of Nephi
20. Lamanite king's land
21. land of first inheritance
22. wilderness (see Alma 43:22)
23. mountain pass
24. Hagoth's possible destination
25. wilderness of Hermounts
26. "line" between Desolation and Bountiful
27. defense "line"

3rd Nephi Location	Sorenson Location Summary
Land northward	south boundary at the Isthmus of Tehuantepec, east boundary at the Gulf of Mexico, west boundary at the Pacific Ocean, north boundary undefined, could range from Veracruz to Mexico City
Land southward	north boundary at the Isthmus of Tehuantepec, east boundary at the Gulf of Mexico, west boundary at the Pacific Ocean, south boundary at south end of the Valley of Guatemala
Zarahemla	Santa Rosa, Mexico
Moroni	north shore of Laguna Mecoacán, Mexico
Moronihah	somewhere in borders by east sea near Jershon
Gilgal	land southward
Onihah	land southward
Mocum	land southward
Jerusalem	south shore Lake Atitlán, Guatemala
Gadiandi	uncertain
Gadiomnah	uncertain
Jacob	uncertain
Gimgimno	uncertain
Jacob-Ugath	possibly Cuicuilco, Mexico
Laman	uncertain
Josh	uncertain
Gad	uncertain
Kishcumen	uncertain

Figure 3 - Possible Location of Destroyed Cities in the Sorenson Model

Figure 4 – Additional Details of the Sorenson Model

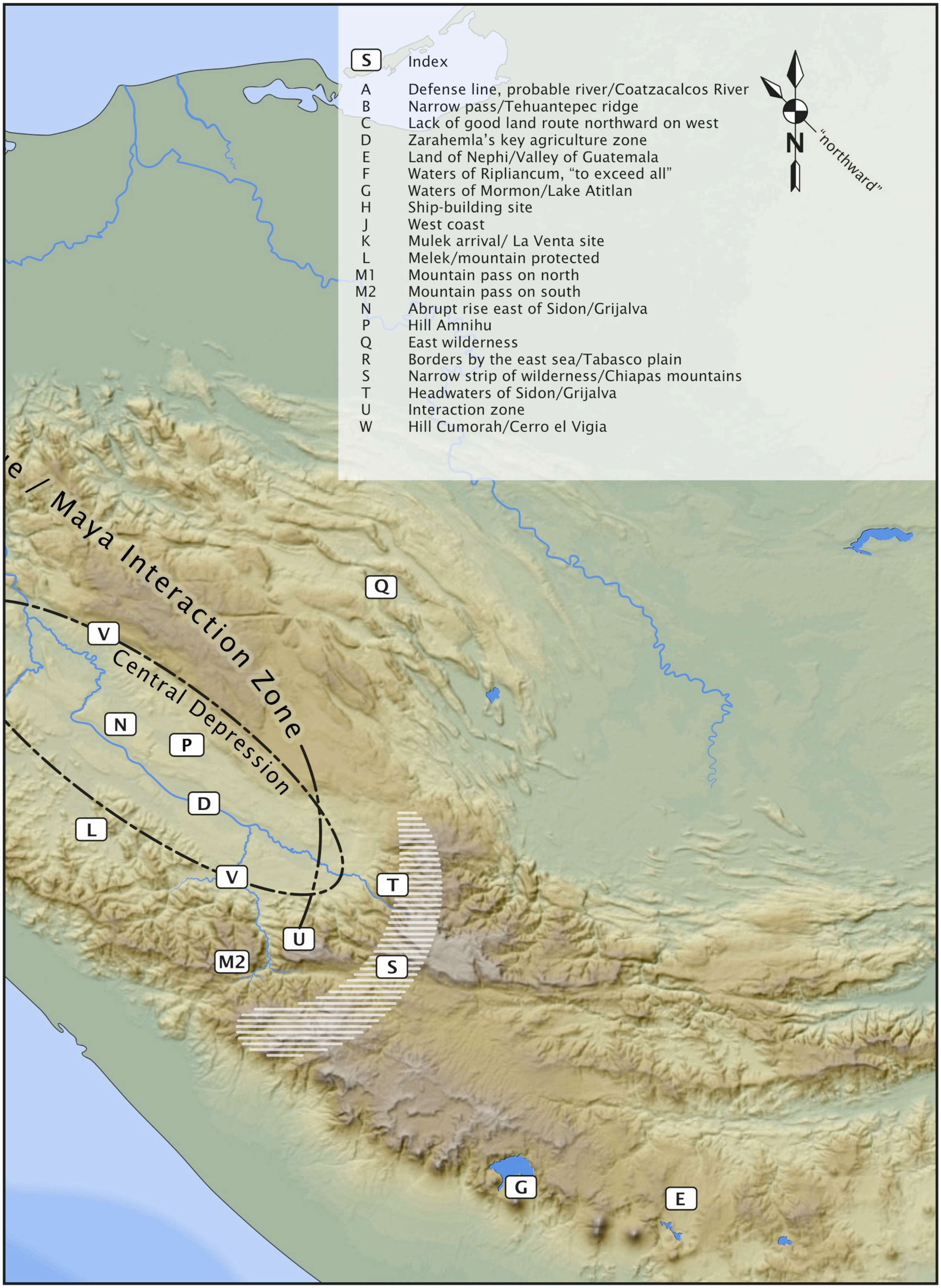

S Index
A Defense line, probable river/Coatzacalcos River
B Narrow pass/Tehuantepec ridge
C Lack of good land route northward on west
D Zarahemla's key agriculture zone
E Land of Nephi/Valley of Guatemala
F Waters of Ripliancum, "to exceed all"
G Waters of Mormon/Lake Atitlan
H Ship-building site
J West coast
K Mulek arrival/ La Venta site
L Melek/mountain protected
M1 Mountain pass on north
M2 Mountain pass on south
N Abrupt rise east of Sidon/Grijalva
P Hill Amnihu
Q East wilderness
R Borders by the east sea/Tabasco plain
S Narrow strip of wilderness/Chiapas mountains
T Headwaters of Sidon/Grijalva
U Interaction zone
W Hill Cumorah/Cerro el Vigia
N
"northward"
e / Maya Interaction Zone
Central Depression
Q
V
N
P
D
L
V
T
U
M2
S
G
E

Figure 5 – Mesoamerican Archaeological Sites and Cities

Dzibilchaltun
Merida
Chichen Itza
Xelha
Tancah
Tulum
Cozumel
Loltun Cave
Edzna
Yucatan Peninsula
Caribbean Sea
Becan
LOWLAND MAYA
El Mirador
Nakbe
Rio Azul
Holmul
Uaxactun
Tikal
Barton Ramie
CULTURE CORE
AltunHa
Palenque
Chiapas
Plateau
iapa de Corzo
Central
Depression
Altar de
Sacrificios
Santa Rosa
Coban
Los Naranjos
Izapa
Quetzaltenango
Highland Guatemala
Copan
Kaminaljuyu
Guatemala City
Samabaj
Esquintla
Balberta/Montaña
Chalchuapa
San Miguel

Chapter 3

General Geology

The purpose of this book is not to give a detailed description of all of the geologic information available for the Isthmus of Tehuantepec, but rather to provide sufficient information to describe the geology related to the destruction described in 3rd Nephi. Also, as non-scientists will be interested in this work, the geologic information is presented in simpler terms than one might find in a scientific journal.

The explanation of volcanoes and many earthquakes is found in the geologic theory of 'plate tectonics,' which involves numerous plates that comprise the outer layer of the earth and move around because of forces in the more liquid mantle upon which the plates sit. Tectonic plates include the oceanic crust and the thicker continental crust.

Since the various plates are moving, along their boundaries they are either colliding with other plates, separating from other plates, or sliding alongside other plates. Boundaries where they are colliding are referred to as 'convergent'; where they are separating, the boundaries there are referred to as 'divergent.' Along convergent boundaries, one plate will typically go underneath the other, which is called 'subduction.' Subduction carries plates down into the mantle; the material lost is roughly balanced by the formation of new (oceanic) crust along divergent margins by spreading, which usually occurs on the seafloor. In this way, the total surface area of the globe remains the same.

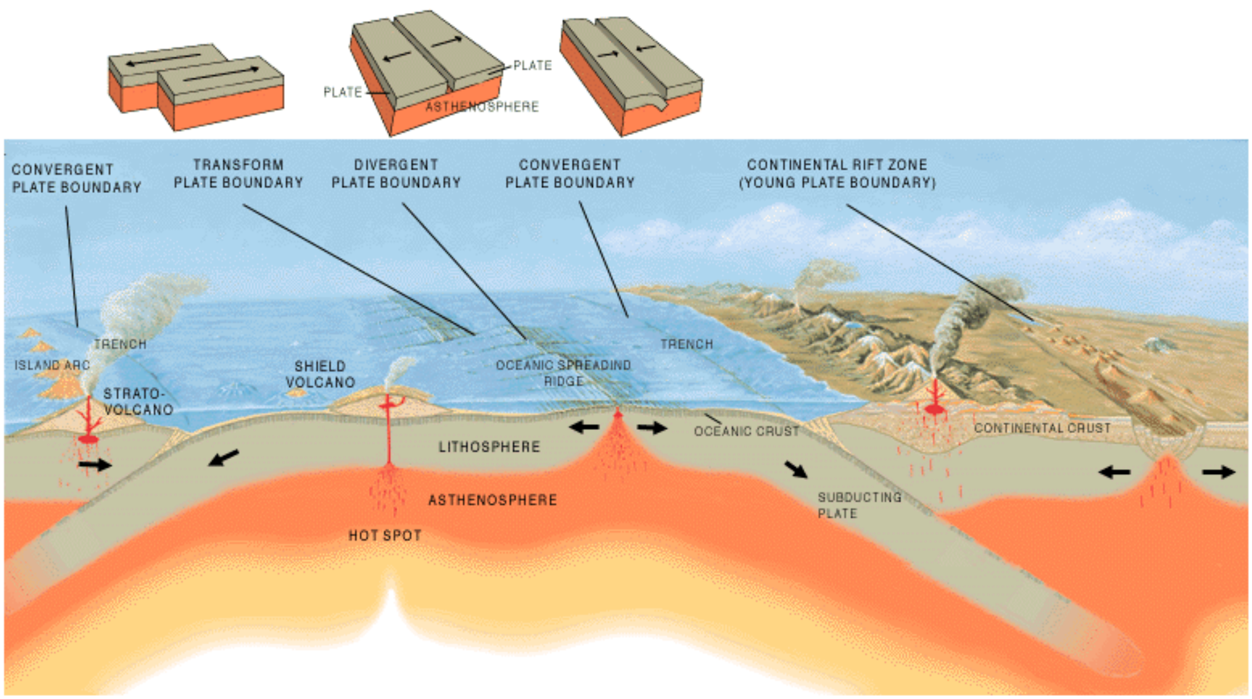


Figure 6. Cross section of plate tectonic model

As a plate is subducted it eventually melts as it enters the mantle. Sediments or rocks that are lighter will melt and form magma, which will migrate back up into the continental crust of the plate under which it is moving. Not all of this magma will make it to the surface in a liquid form, but when it does, a volcano or lava field results. In a divergent plate boundary, magma also comes to the surface and forms an oceanic ridge. There are other areas called 'hot spots' where magma can also come to the surface and form volcanoes. Hawaiian volcanoes are the result of a hot spot. A theoretical diagram showing a cross-section of plate tectonics is shown in figure 6.

In the case of the Isthmus of Tehuantepec, the Cocos Plate, which lies to the south and west, is being subducted underneath both the Caribbean Plate and North American Plate at certain locations, creating a string or group of volcanoes, which are called 'volcanic arcs' (see figure 7).

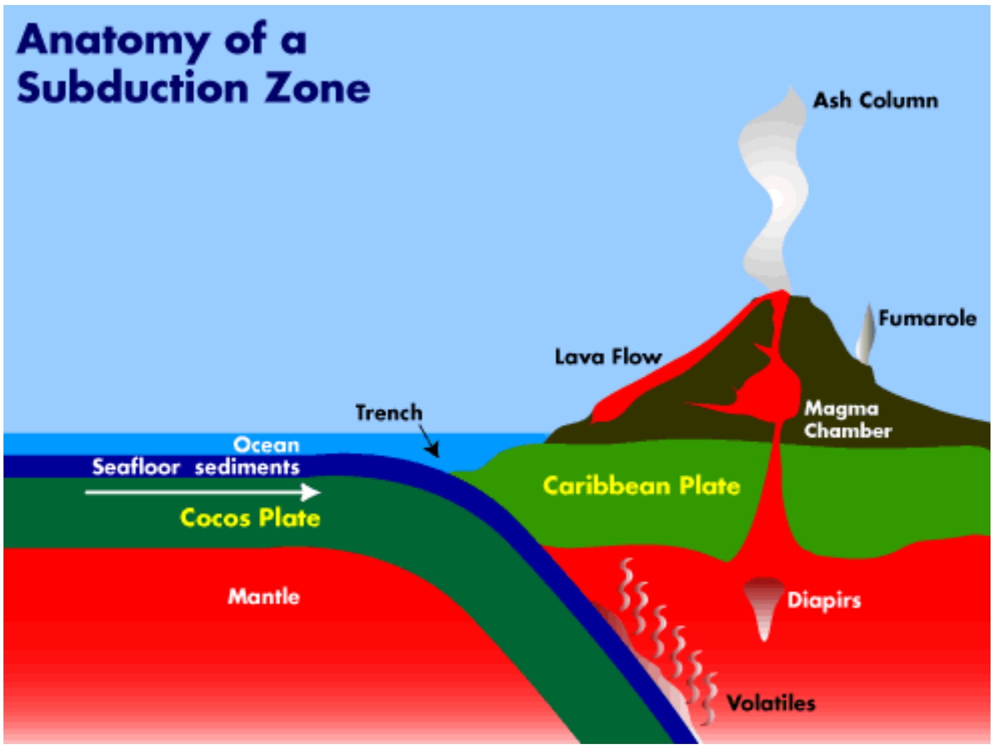


Figure 7. Typical subduction zone at the Isthmus of Tehuantepec

The subduction of the Cocos Plate underneath the Caribbean and North American plates is not uniform in the angle of subduction. When subduction occurs under two plates along their boundary the situation becomes complex. In addition, there appears to be some rifting or divergence underneath the west side of the Isthmus that complicates the formation of the volcanic areas and which types of magma and volcanoes form. Scientists do not appear to have reached consensus on exactly what is occurring here. Figure 8 shows a bird's-eye view of the Cocos plate subduction process going on at the Isthmus. The pink areas are the different volcanic arcs or areas. They are labeled with abbreviations as follows:

CMVB: Central Mexican Volcanic Belt

MCVA: Modern Chiapanecan Volcanic Arc

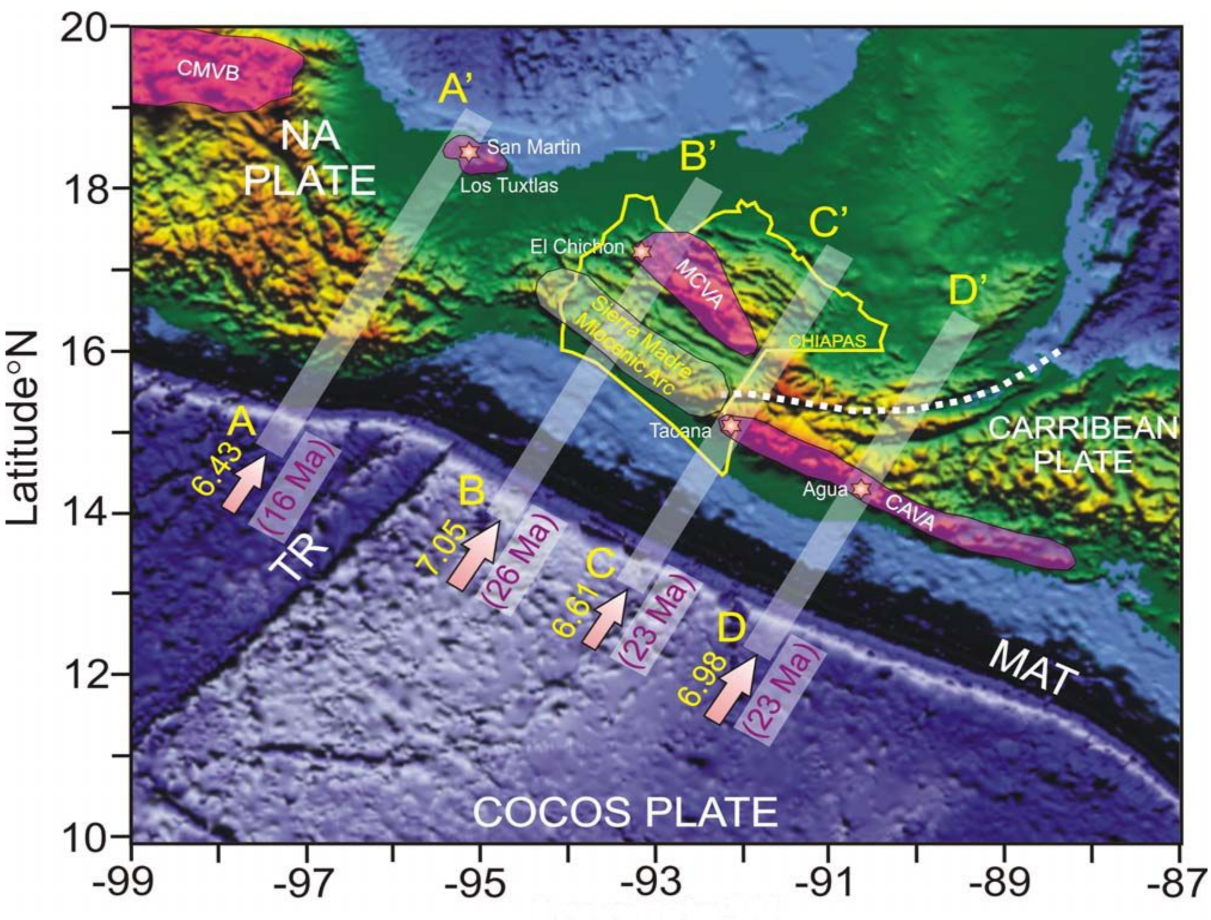
CAVA: Central America Volcanic Arc

MAT: Middle America Trench

Los Tuxtlas: The Tuxtla Volcanoes are often referred to as the Tuxtla Volcanic Field (TVF)

TMVB: Trans-Mexican Volcanic Belt

As geology is a three-dimensional science, in that one has to determine the situation underneath the surface of the earth as well as at the surface, geologists use what are called 'cross-sections' as depictions. Figure 8 shows four separate lines, A to A', B to B', C to C', and D to D'. If one imagines making a slice down through the earth along one of the lines and imagines looking at the cut section from the side, one would see what is shown in figure 8. This would be similar to cutting through a layered cake and looking at the slice from the side.



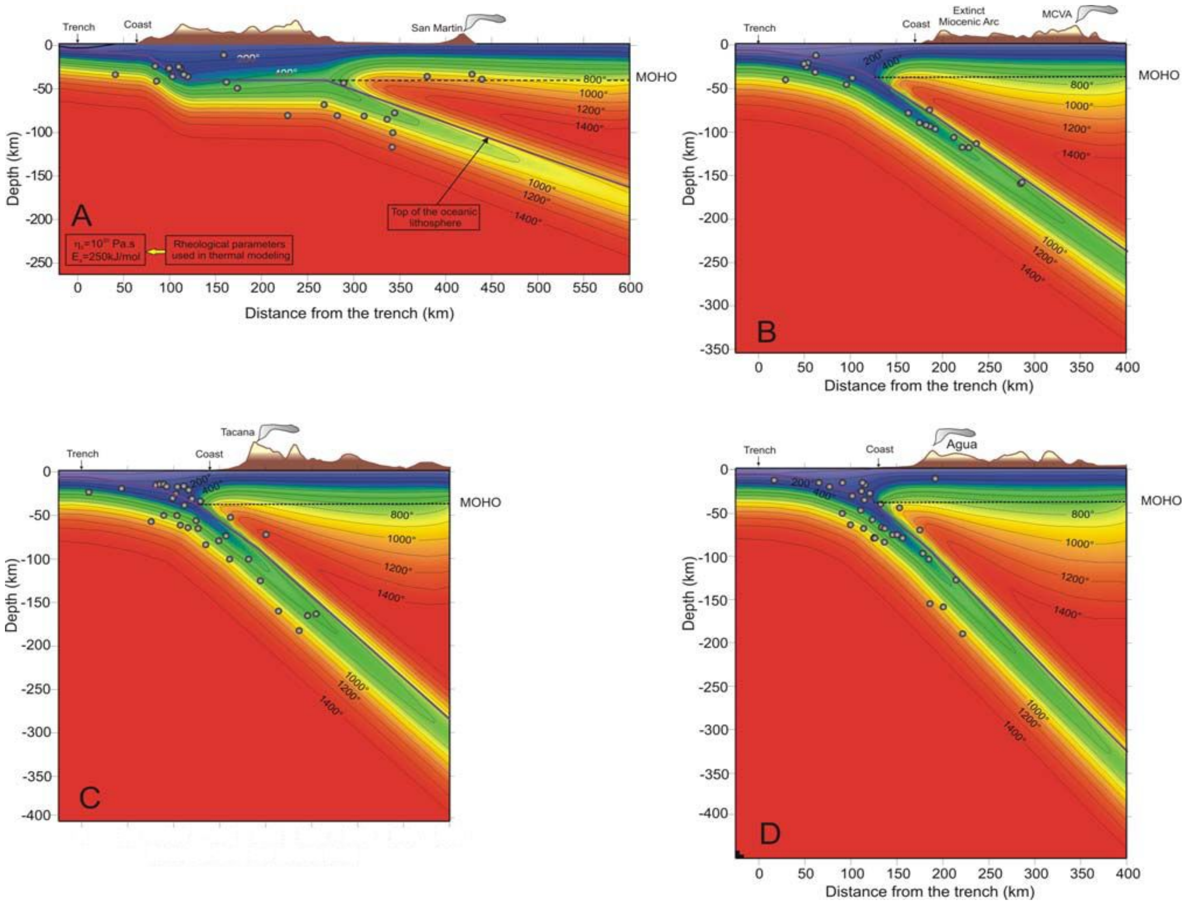


Figure 8. Cocos Plate subduction and volcanic arcs or belts and cross-sections (Manea and Manea, 2006, 29–30)

Isthmus of Tehauntepec Fault Zones Earthquakes

Figure 9 shows that the geology in the Isthmus becomes a bit more complicated because it not only involves the subduction of the Cocos plate, but also involves the relationship and boundary movement between the North American and Caribbean Plates. While somewhat of an oversimplification, the North American and Caribbean Plates are sliding alongside of each other to some extent, with the North American Plate rotating and sliding to the west and northwest and the Caribbean Plate sliding to the east. Figure 9 contains arrows that show the direction of movement, indicating the direction of movement of the plates. As is evident, it is a bit messy, as some areas are not sliding but are actually undergoing compression (arrows pointing directly at each other) while some other areas are undergoing tension (arrows pointing directly away from each other).

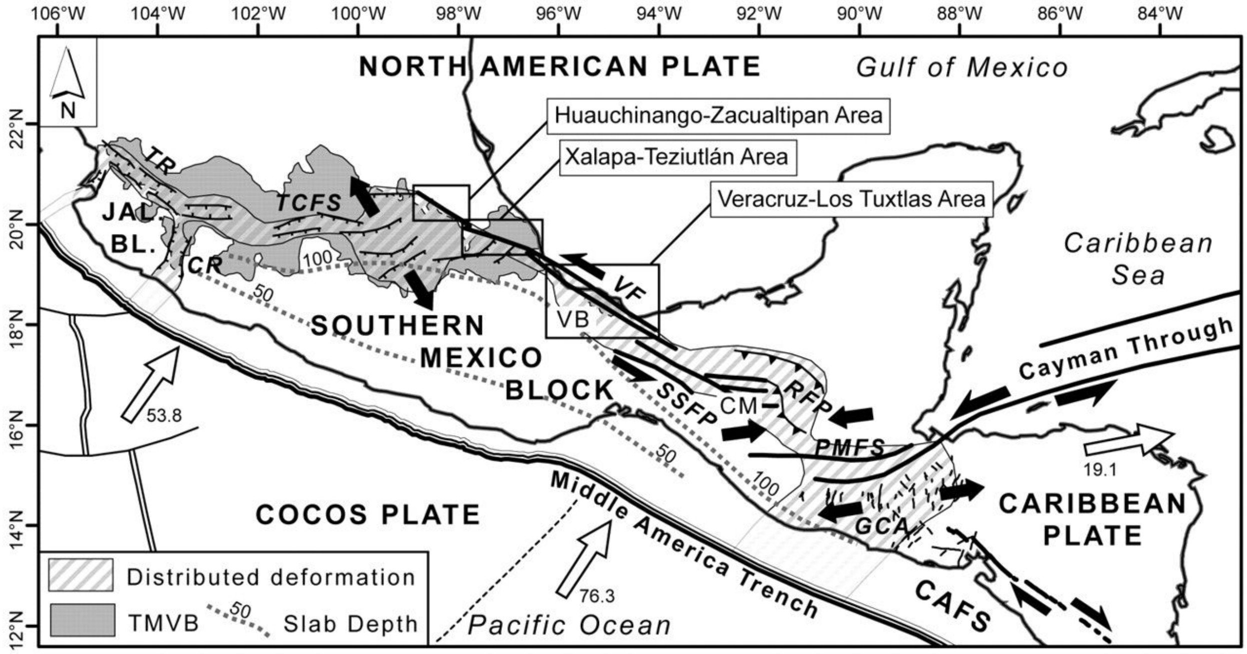


Figure 9. General geologic structure map of the Isthmus of Tehuantepec (Andreani et al., 2008)

At this juncture it would be useful to discuss the general nature of faults. There are three kinds of faults, strike-slip (lateral), normal (block), and reverse (thrust) fault (see figure 10). All three of these types of faults are present in the Isthmus of Tehuantepec.

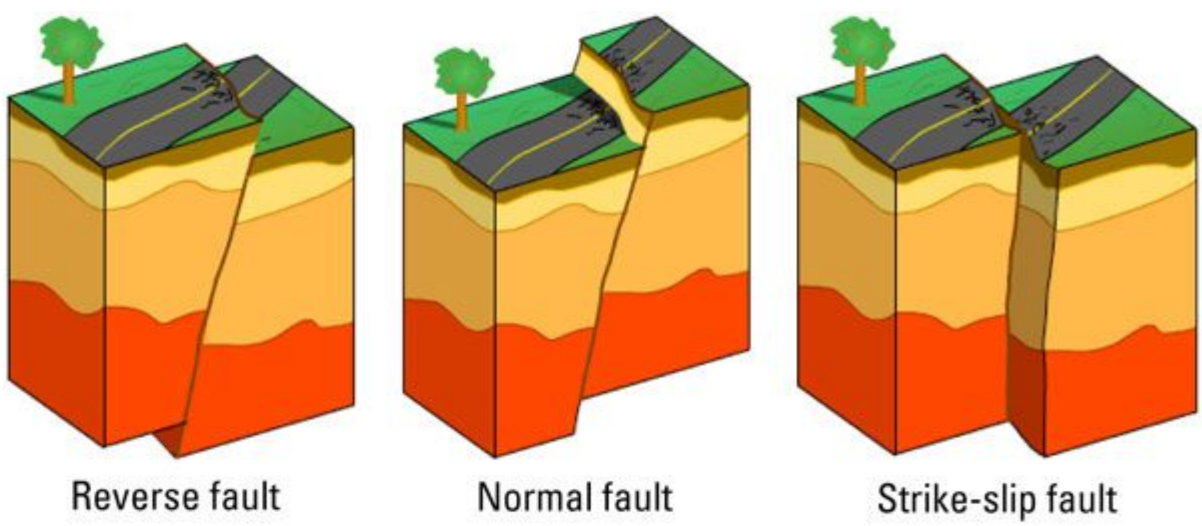


Figure 10. Types of faults

The type of faulting that occurs depends on the type of pressure or tension that is being exerted on that particular section of the earth's crust. The earth's crust responds to the differing pressure environments by folding or fracturing. Figure 11 displays the typical folding and fracture responses.

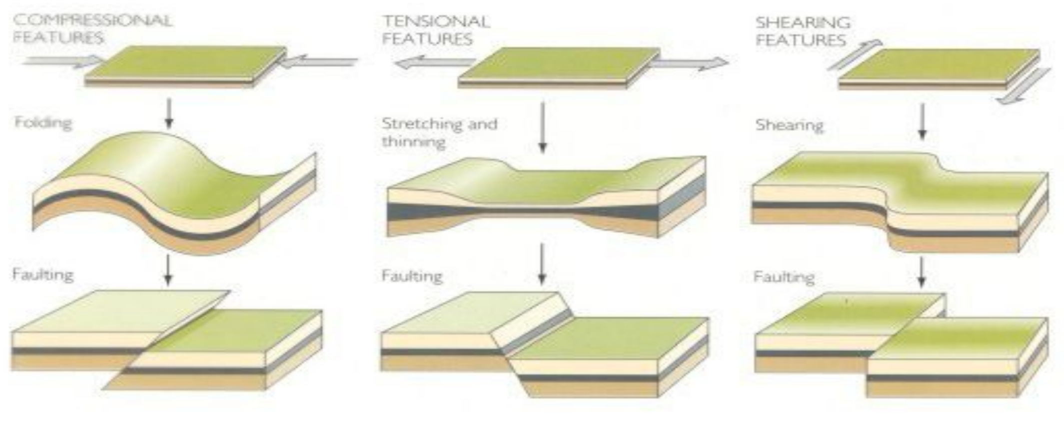


Figure 11. Crustal response to compression, tension, and shearing pressure

There are two main zones or provinces of regional faulting in the Isthmus of Tehuantepec. Figure 12 shows the principal areas of faulting and recent (in geologic time) earthquake activity with earthquakes exceeding a magnitude of 4. The different colors show the depths of the earthquakes. The figure also shows blue and white "beach balls," which are figures that geologists use as a convenient 2D way to depict the 3D type and movement of a given fault. These "beach balls" are depictions of what is called the focal mechanism. Figure 13 shows the types of faults that each of the "beach balls" represent.

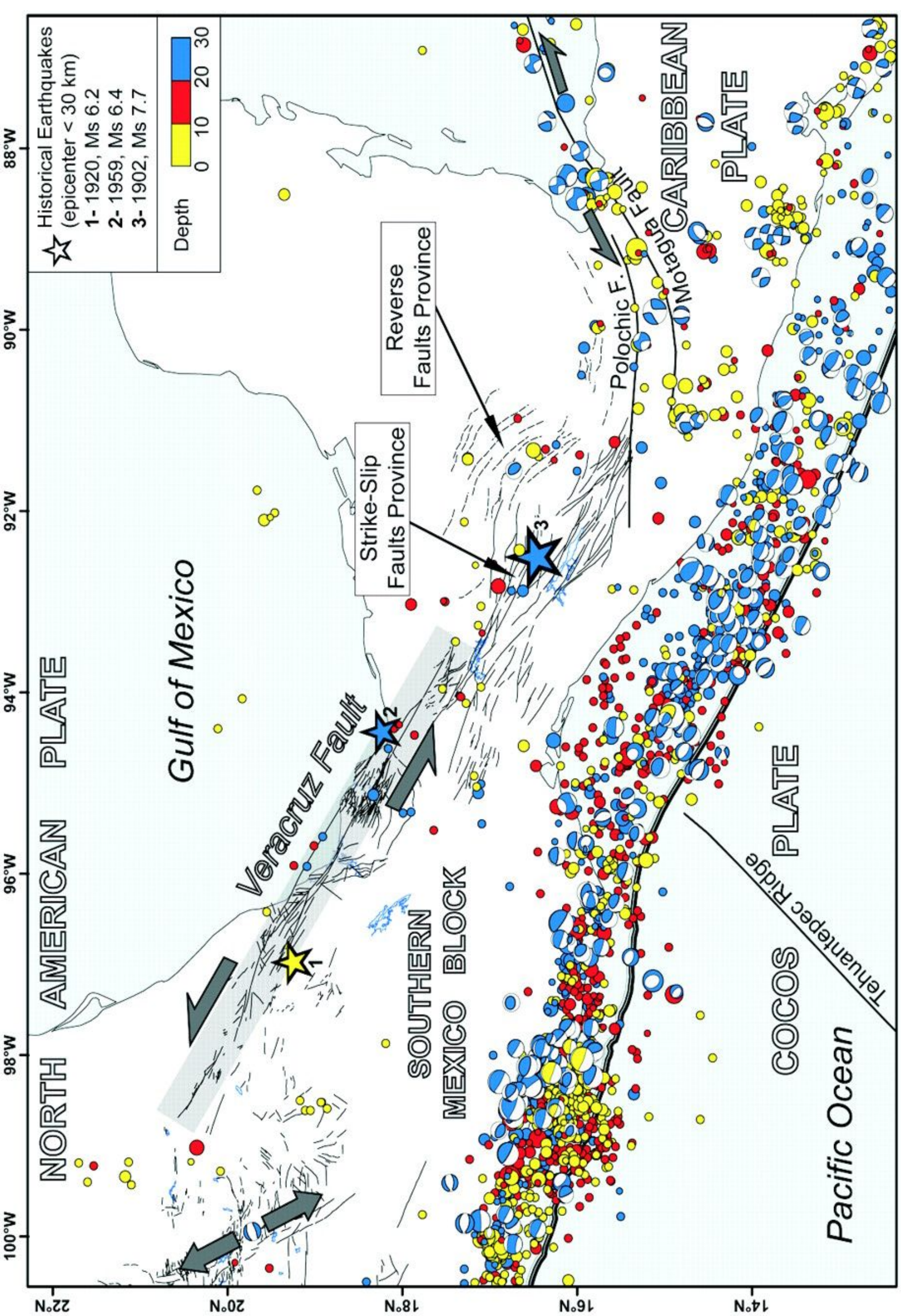


Figure 12. Locations of shallow (< 30 km) and Ms > 4 earthquakes outlining the main plate boundaries (Andreani et al., 2008)

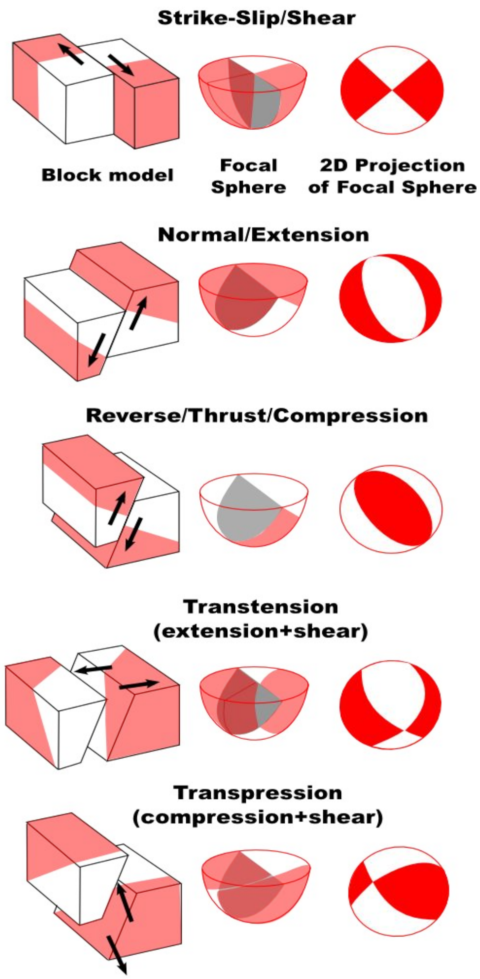


Figure 13. Focal mechanism depictions

Pacific Coast Subduction Fault

The first faulting area, and the most active zone, is along the Pacific Coast where the Cocos Plate is being subducted. This area consists principally of compressional faulting at depth along the subduction zone, with surface faults being normal faults with some strike-slip elements. Many of these faults may be deep faults with little or no surface expression. As a general rule, in the subduction zone shallow earthquakes are nearer subduction trenches and get deeper as the plate is further subducted. Shallow faulting at the earth's surface above the subduction zone away from the trench typically contains normal and to a lesser extent, strike-slip faulting. It should be noted that in both fault provinces, all three types of faults are typically present, the province is classified for the general regional pressure regime and the most dominant types of active faults.

Veracruz-Polochic/Motogua Strike-Slip Fault System

As indicated in figures 9 and 12, there is a long active strike-slip fault system that runs from the northwest to the southeast through the Isthmus of Tehuantepec. It does not produce near the number of earthquakes as the Pacific Coast Subduction area, however it does produce large shallow earthquakes periodically. The northwest end of the fault zone transitions into a tensional fault system. The province consists of the main Veracruz fault system that runs southeast through the neck of the isthmus, with a transition step-over area consisting of numerous strike-slip offset faults before it connects with the main Polichic/Motagua strike-slip segment to the south. There is an area of reverse faulting northwest and adjacent to the central strike-slip transition area.

Isthumus of Tehuantepec Volcanoes

Each of the Isthmus volcanic arcs, belts, and fields has multiple volcanoes, volcanic cones, and lava flows. Figure 14 shows the location of the principal volcanoes. Some of these volcanoes are no longer active and were not active during Book of Mormon times. This factor will be used to narrow down the list of potential volcanoes that may have been involved in the 3rd Nephi catastrophe.

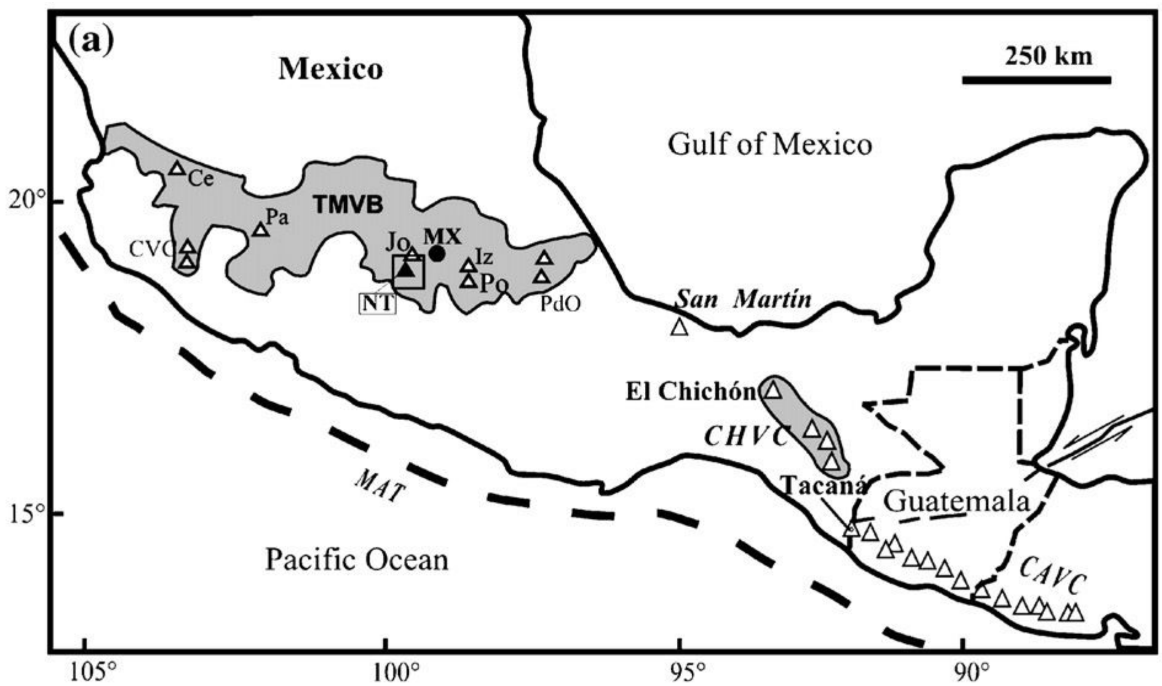


Figure 14. Volcano locations (triangles) in Southern Mexico and Guatemala (Bellotti et al., 2006)

Before commencing a discussion of individual volcanoes, it is necessary to delineate some general systems used in the classification of volcanoes and volcanic eruptions. There are a variety of systems and methods to classify volcanoes. This book will just present a few of the basic systems. The first classification of volcanoes is related to the shape and to some extent the type of the magma source. There are many varieties of compositions of magma, however, one of the principal parameters of magma that influence the volcano form and the nature of the eruption is the viscosity of the magma.

Viscosity means a fluid's ability to flow. A fluid that has high viscosity flows very slowly, like cold honey, whereas a fluid with low viscosity flows easily, such as water. Magma that has low viscosity produces lava that flows easier and thus produces thinner and flatter deposits like the fissure and shield volcanoes shown in figure 15. Some volcanoes form and erupt only once; they are called monogenetic volcanoes. For the most part, the volcanoes that will be discussed in this book are not monogenetic, but have erupted and formed various levels of layered deposits on their flanks like the composite volcano shown in figure 15.

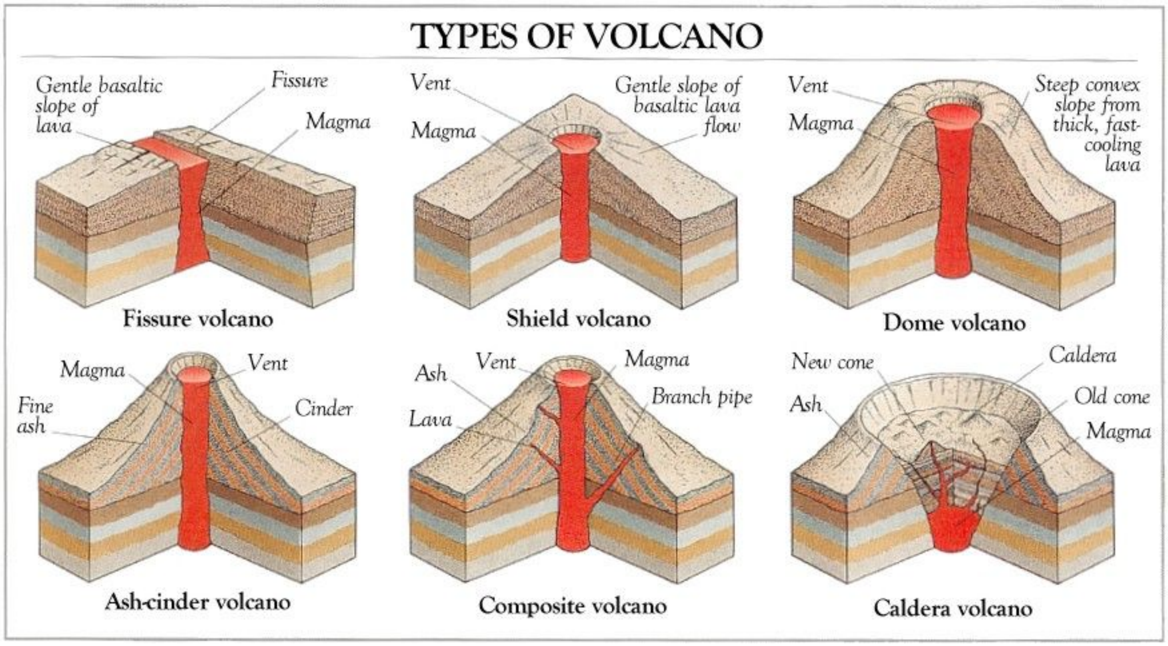


Figure 15. Volcano forms

Volcanic eruptions are classified both by their form and by their explosive power. The eruption forms are illustrated in figure 16. Keep in mind that these are just general forms; each volcano and each volcanic eruption is unique, and some volcanoes can exhibit more than one type of eruption. The power of a volcanic eruption is classified using the Volcanic Explosive Index or VEI, which consists of a numbering system from 0 to 8 with 8 being the most explosive. Figure 17 is a chart that shows the VEI scale and how the VEI generally relates to other features of volcanoes.

The nature in which material is expelled from a volcano also has different names and descriptions. The common types are shown in figure 18. Pyroclastic flows are especially deadly as they consist of superheated volcanic ash and volcanic rocks debris that travels at high speed, generally along the ground surface (see figure 19). Lahar flows occur where water is present, either in the form of snow, rain, groundwater, or surface streams and rivers (see figure 20). In a lahar the volcanic ash and other volcanic materials combine with the water and form a heavy mud that has the consistency of concrete slurry. These are also extremely deadly as they can contain huge amounts of material, travel quickly, and follow drainage channels through which the volcanic materials travel well beyond the obvious eruption area. Volcanoes generate fragmentary debris, everything from large house-size boulders to finely crushed rock material, to magma explosively sprayed in a mist of molten droplets and fragmentary glass and crystals. The term 'ejecta' is used for anything blasted out of an exploding volcano. The term 'tephra' describes air fall ejecta and typically includes blocks, bombs, and lapilli (gravel sized material) that fall back to earth; these are referred to as ballistic particles. Tephra also includes ash and dust that become entrained in the air and spend time drifting, generally windborne, before falling back to the surface.

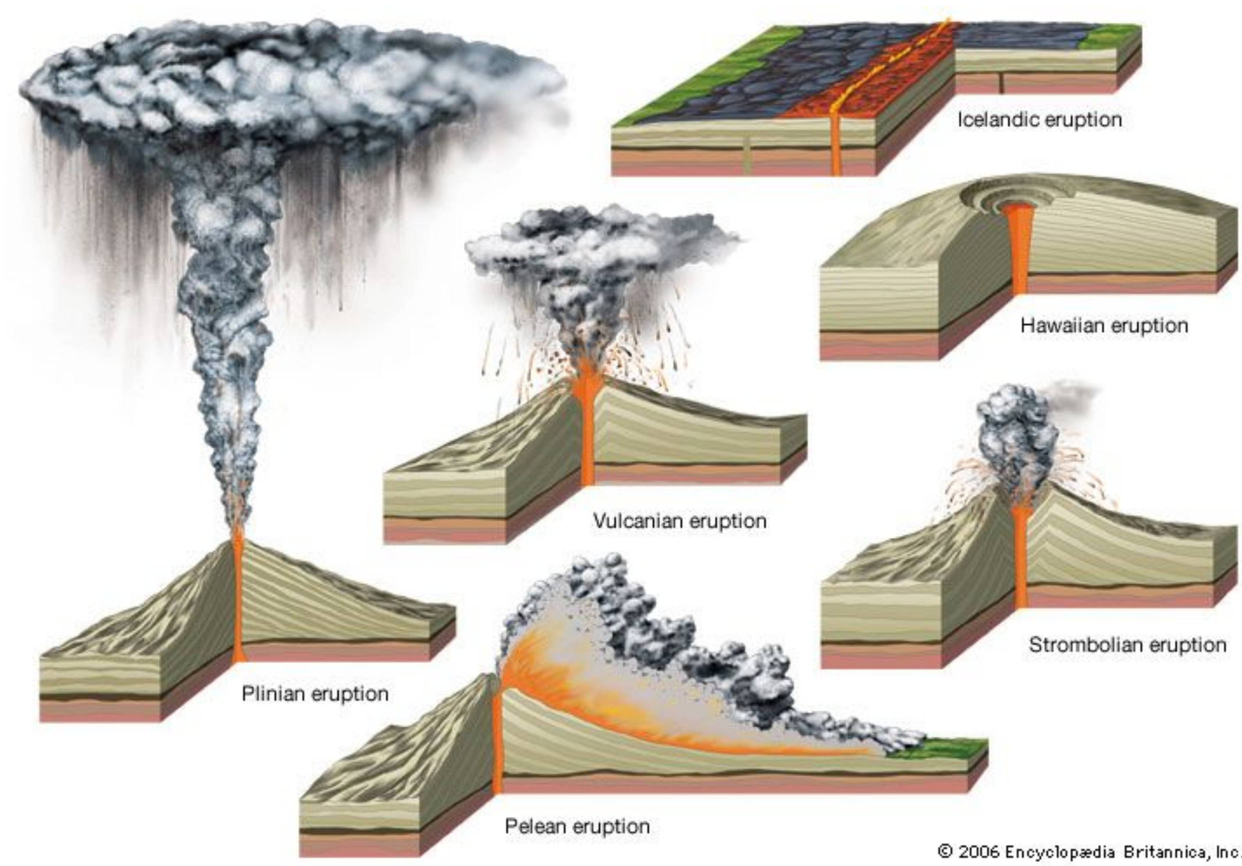


Figure 16. Volcanic eruption forms (courtesy Encyclopedia Britannica, 2006)

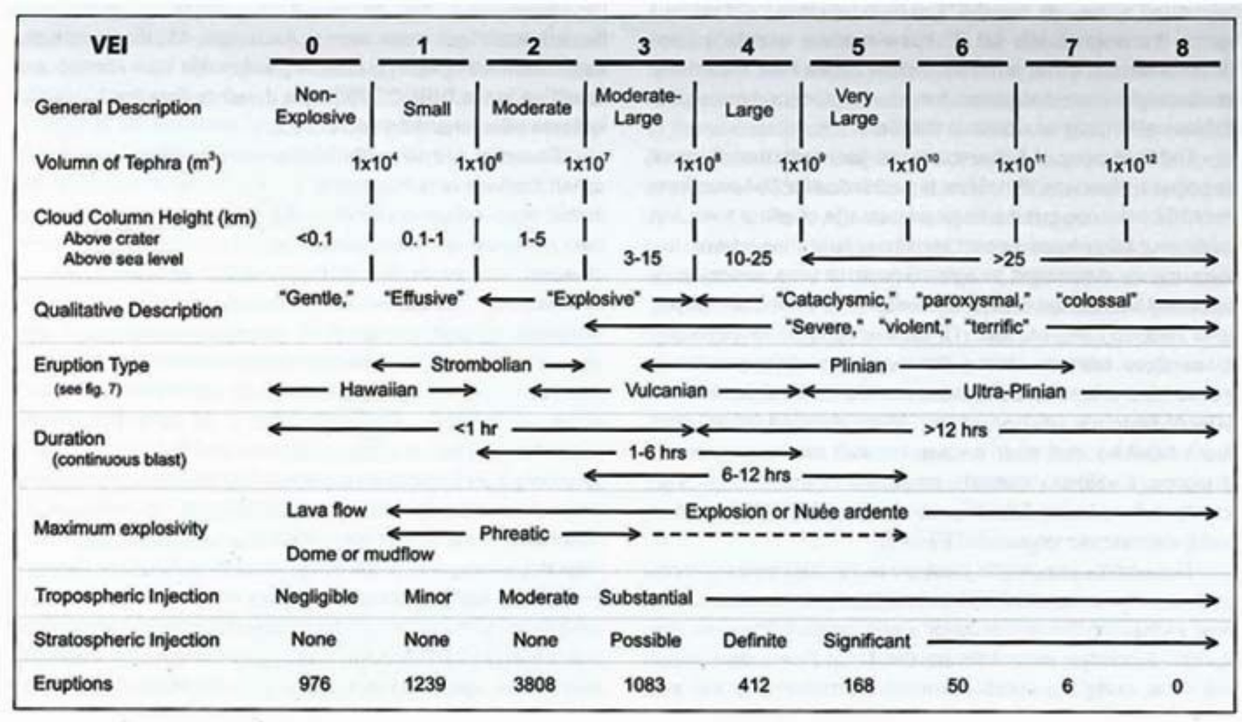


Figure 17. Volcanic explosive index chart

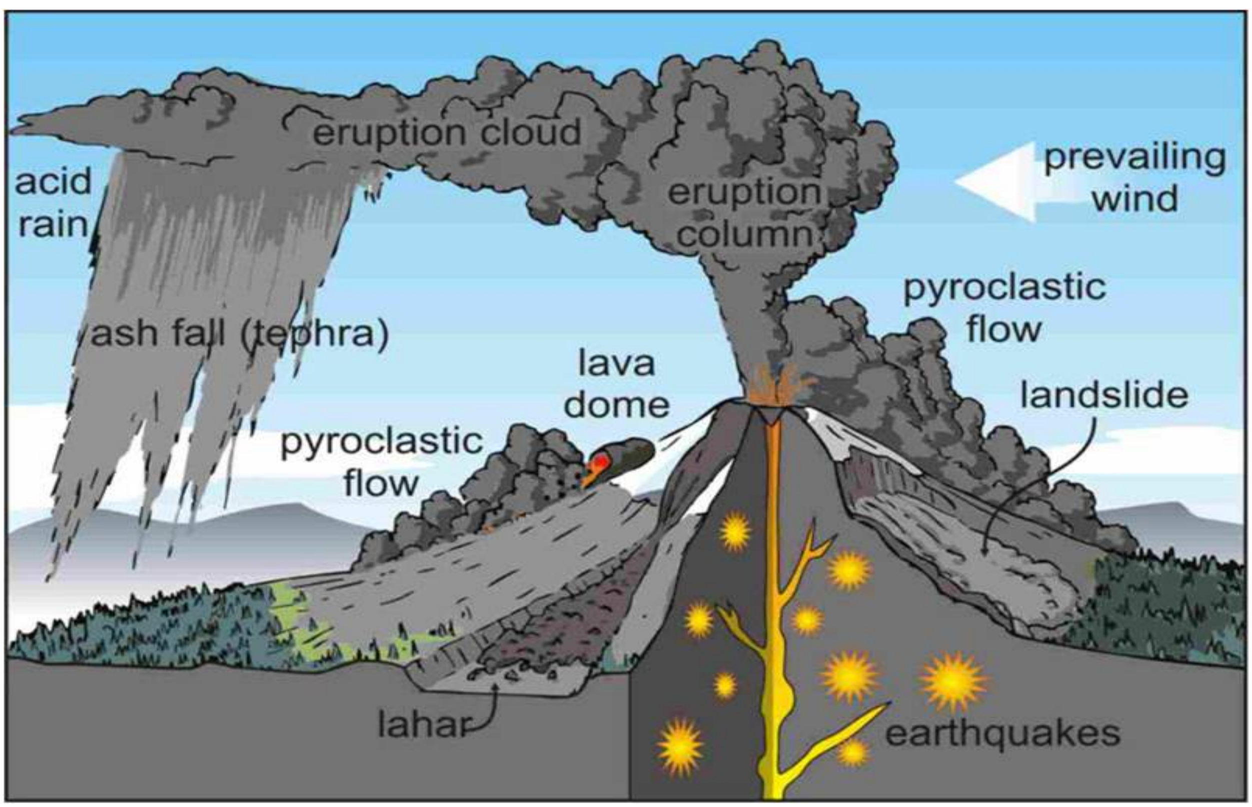


Figure 18. Volcanic deposition types

Figure 19. Pyroclastic flow from the 1991 Mount Pinatubo eruption (courtesy Wikipedia.org)

Figure 20. Lahar flow from the 1982 eruption of Galunggung, Indonesia (courtesy Wikipedia.org)

Volcanoes also emit large volumes of gases during eruptions, the bulk consisting of water, carbon dioxide, and sulfur and sulfur oxides. Very minor amounts of helium and halogens are also present.

Individual Volcanoes in the Isthmus

Each of the volcanoes within the Isthmus will be briefly discussed. Volcanoes located in the land northward that have activity during Book of Mormon times will be discussed in greater depth. It is important to note that the historical volcanic eruption data will invariably be incomplete. It is clear after a review of the literature that the rainy semi-tropical climate of the Isthmus has eroded and obliterated many of the volcanic deposits, even those as old as just a few hundred years. In addition, subsequent eruptions cover up evidence of prior eruptions. Finally, some of the volcanoes have not had thorough geological investigations to differentiate historical volcanic deposits. There may be other eruptive events during the period of 3rd Nephi that are yet to be discovered, or whose evidence is no longer present.

It needs to be noted that for nearly all of the historic eruptions, the method used for confirmation of the date ranges is radiocarbon dating based on atmospheric amounts of ^{14}C. As with any other sampling and laboratory method, there are possibilities for error, so care needs to be taken when a particular eruption date is supported by a single sample. Generally speaking, for purposes of this book, unless otherwise noted, the assumption is made that the radiocarbon date has been established using a sample that has been replicated to what scientists call the $\pm 2\sigma$ level, for which there is a 95.% chance that the date lies within the date ranges given. Some sources did not list the level of accuracy of the sample data, so further investigation may be expected to modify those results. Of course, this level of accuracy is for the lab results, there can be errors that occur in the original sample. In addition to error from contamination of the sample, volcanoes, whether active or apparently dormant, produce carbon dioxide gas that can skew radiocarbon dating because they locally dilute the atmosphere with carbon that has no ^{14}C activity, which local vegetation may have absorbed prior to burial (Bowman, 1990, 26).

This is not to imply that radiocarbon dates are not accurate in volcanic environments, but it does suggest that the more samples that are taken the better, and that there may be data disagreements among scientists on the same volcano that may only be resolved by looking for correspondence from other types of sampling or historical sources. The volcanic eruption of the Xitle volcano, which covered the city of Cuicuilco near Mexico City, is a perfect example. The site may have been tested more than any other volcanic site in the Americas, yet the radiocarbon dating by different archeaologists has swung in a range of 2500 years (Gonzalez et al. 2000, 218). It is best to keep an open mind on the identification of 3rd Nephi volcano(s) when considering radiocarbon dating of eruptions as a parameter.

Volcanoes in the Land Northward

For purposes of this book, volcanoes beyond the Mexico City basin at a distance of 600 kilometers from the boundary of the land northward and the land southward are not considered, as the distance would seem to be too great to be relevant to the Book of Mormon area; furthermore, the Sorenson model doesn't have any discussions of sites beyond that boundary. The volcanoes for which the current data showed activity at or close to the 3rd Nephi time frames are shown on figures 21, 22, and 23 with red labels; those that were historically active but with insufficient data to show activity in the 3rd Nephi time frames are delineated with pink labels. Detailed discussions will only be made for volcanoes with documented eruptions within the 3rd Nephi time frames.

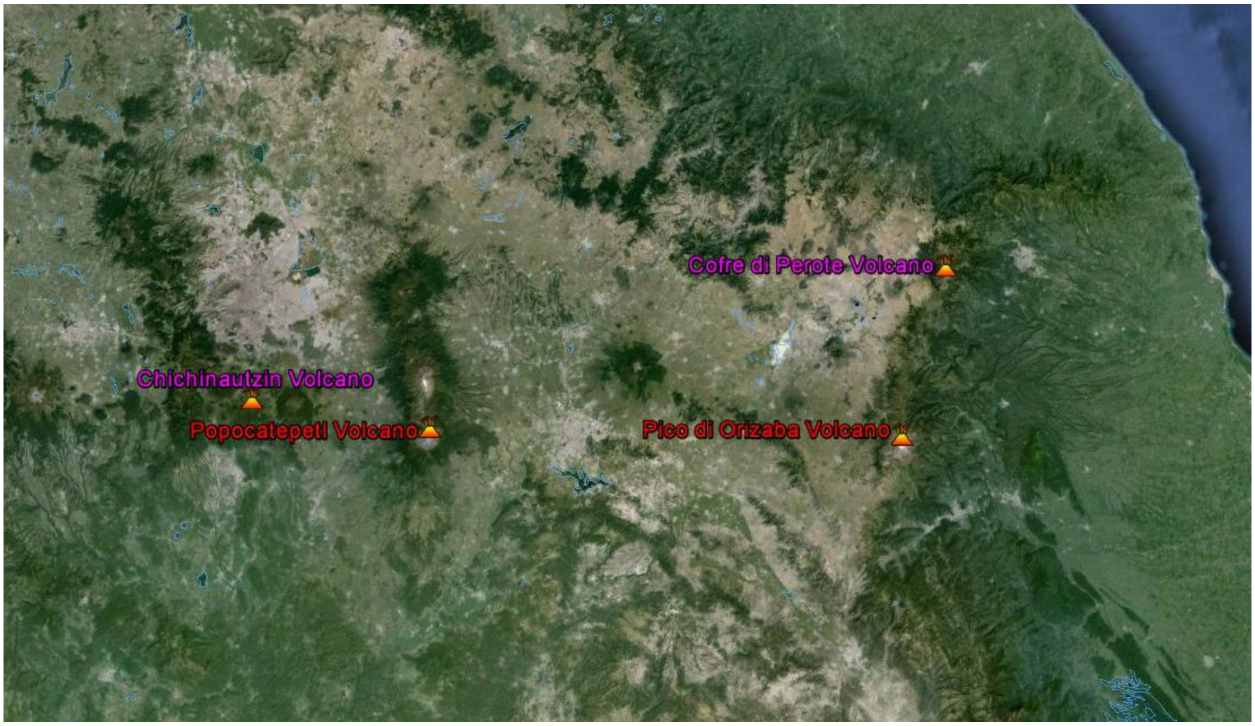


Figure 21. Northernmost volcanoes

Figure 22. Volcanoes located near the boundary of the land northward and the land southward

1. San Martín volcano (Tuxtla Volcano Complex)

The San Martín Volcano is a massive alkaline shield volcano located in the land northward and the flanks of the volcano extend to the Gulf of Mexico (see figure 23). It is elongated in a NW–SE direction and is capped by a 1-km-wide summit crater. The upper part of the 1650-m-high volcano is covered with dense tropical rain forests. The summit and flanks of San Martín are dotted with more than 250 pyroclastic cones and maars. Well-preserved cinder cones are abundant between the summit of the volcano and Laguna Catemaco on the SE flank. The San Martín volcano is located on the northwest end of the volcanic complex, which consists of other inactive volcanoes to the southwest.

It is the highest peak within the Tuxtla Volcanic Field (TVF), also known as Los Tuxtlas Volcanic Field or Los Tuxtlas Massif, which consists of hundreds of cinder cones, maars, and three additional large volcanic edifices mostly dormant since late Pliocene: Santa Marta, San Martín Pajapan, and Cerro el Vigía. A maar is a broad, low-relief volcanic crater that is caused by a phreatomagmatic eruption, which is an explosion caused by groundwater coming into contact with hot lava or magma (see figure 24). A cinder or scoria cone is a steep conical hill of tephra (volcanic debris) that accumulates around and downwind from a volcanic vent (see figure 25).

A phreatomagmatic eruption is produced by flash vaporization of water due to rapid energy transfer from the magma by superheating. These eruptions began suddenly, without any warning activity (e.g., felt seismicity).

Figure 23. San Martín Volcano (Smithsonian, 2014)

Figure 24. Maar crater in the Pinacates Mountains near Rocky Point Mexico

Figure 25. Example of a cinder cone volcano in Parícutin, Mexico

The San Martín volcano is located directly on the lineament of the Veracruz fault system (see figure 26). A detailed geologic structural map shows the extent to which the San Martín volcanism is related to the Veracruz fault structure (see figure 27). Eruption patterns generally follow the direction of the fault traces that make up the Veracruz fault system.

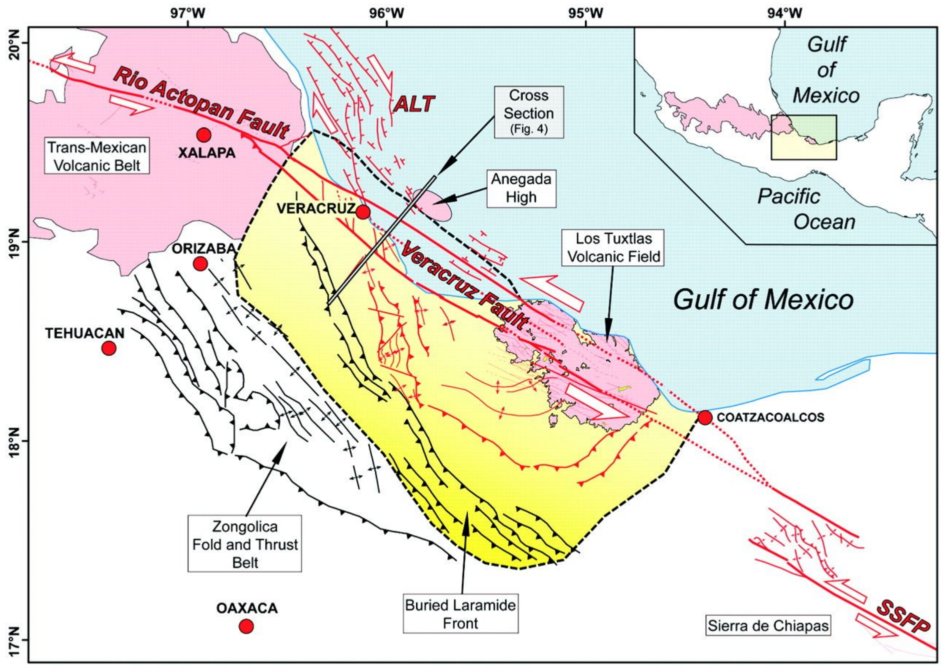


Figure 26. Location of the Tuxtla Volcanic Field and the Veracruz Fault (Andreani et al., 2008)

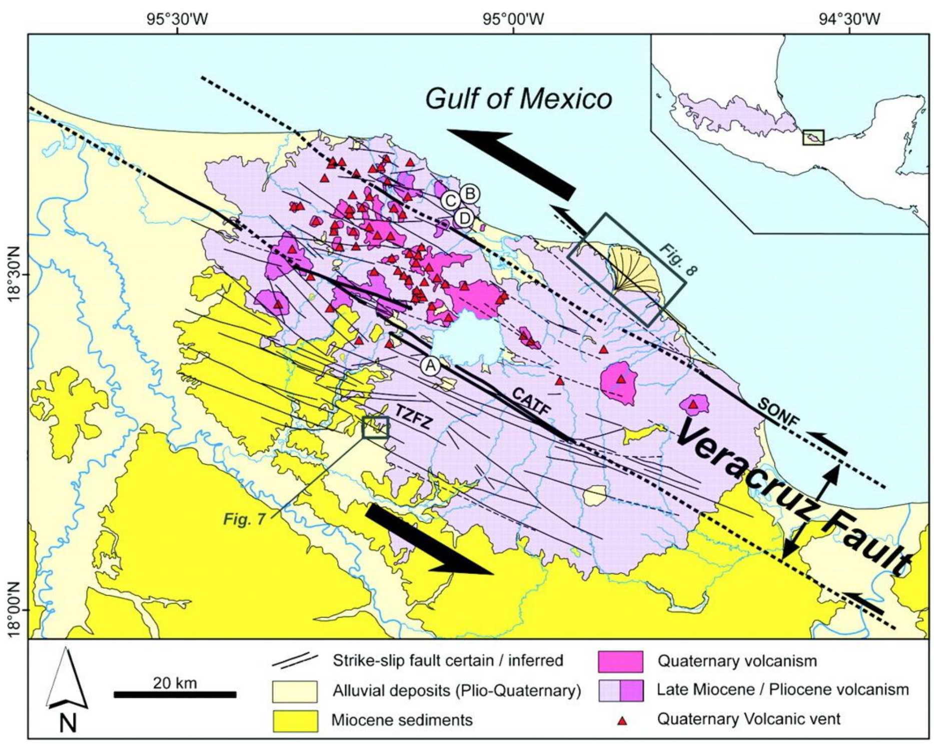


Figure 27. Detail of geologic structure of the Tuxtla Volcanic Field (Andreani et al., 2008)

In addition to the geologic maps that show past volcanic eruption depostion, recent hazard assessment modelling as shown in figure 28 has identified anticipated lahar mud flows from the San Martín volcano. As is apparent from all of figures 26–28, it is clear that past volcanic eruptions and lahar flows reached the Gulf of Mexico, raising the possibility of historic generation of tsunami events in the Gulf of Mexico.

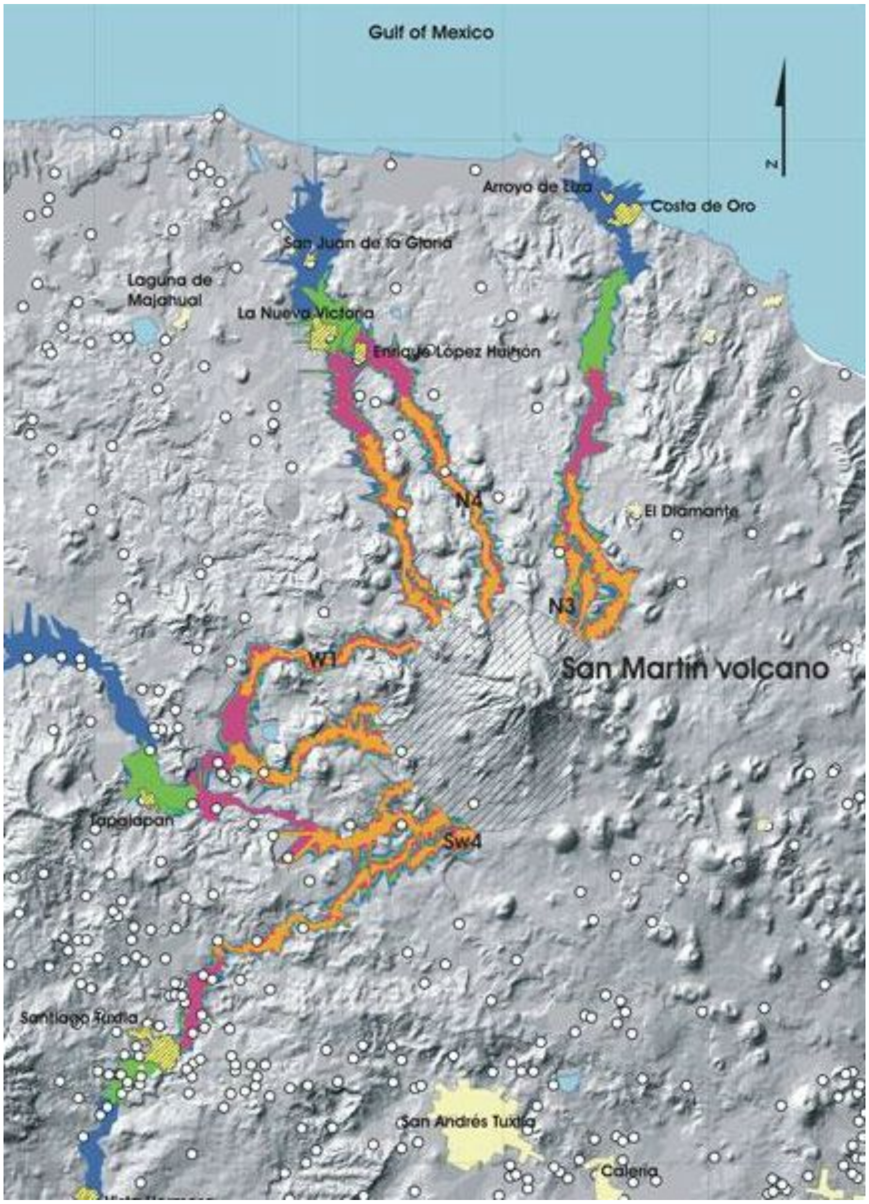


Figure 28. Anticipated lahar flows from the San Martín volcano (Sieron et al., 2014, 290)

Eruption of San Martín in 1793

The last significant eruption of San Martín was a VEI 4 phreatomagmatic eruption in 1793. The effects and extent of the eruption were documented by Dr. Joseph Mariano Moziño. Moziño was a naturalist born and educated in New Spain. The eruption began on March 2, 1793, during the afternoon. Since heavy clouds covered the mountain and thunderstorms were frequent in its vicinity, most of the people took the explosive sounds as those of a large thunderstorm. A couple of hours later, however, the cloud cover disappeared, driven by the winds, and people were able to see:

> … a large column of fire … towards the northeast of Tuxtla and north of San Andrés; many thunderbolts stemming from its center and zigzagging in different directions,

> frightened the eyewitnesses and rushed the crowds to the temples to implore for divine mercy thinking that, if not the complete ruin of the universe, at least that of the region was inevitable. Translated from Moziño (1870, 63)

On March 3rd, explosions were heard at the villages of Perote, Teziutlan, Jalacingo, Papantla, Misantla and Andrés Chalchicomula (now Ciudad Serdán), towns located at distances as far as 300 km from the volcano, and were taken as cannonades against pirates at the port of Veracruz. More than 400 "cannon shots" were counted at Papantla and Misantla.

The second eruption, which lasted for about two days, began on May 22nd in the morning. As the wind was blowing from the north:

> The height of the fire column was much greater than the first time, with more frequent lightning, a more widespread cloud of smoke and heavier ash fallout. The sun was so much darkened that in a radius of more than 15 leagues *(83.5 kilometers)* it was necessary to use artificial lighting at noontime. Translated from Moziño (1870, 64)

By May 23rd, ashfall reached the towns of Oaxaca, Izucar, Tehuacán, Orizaba, Córdoba, and the province of Tabasco (with the principal towns then being Villahermosa and Tacotalpa). All the towns were located about 230 km and 320 km from the volcano in different directions.

A third eruption occurred on the morning of June 28th. This was the largest eruption and the southern winds carried the ash towards the sea and the hills of Tecolapan (northwest of the volcano). As a result, the roads in that area were so much disfigured that passage was impossible. Woods were set aflame during the 3 days that the eruption lasted.

In September Moziño visited the volcano and observed that the fallout was from at least 3 yards and up to 6 yards thick located in a circle around the volcano with a diameter of 2 leagues (11.1 kilometers).

In addition to the towns identified by Moziño as showing the extent of the distribution of the ash fallout, the ash from the 1793 eruption has also been identified in 2 marsh sediment cores taken about 150 km north of the El Chichón volcano (Nooren, 2009). A map showing the approximate extent of the 1793 ash distribution from volcanic eruption using this data together with the towns identified by Moziño is included as figure 29.

The description of this eruption has some interesting parallels with the account in 3rd Nephi including the onset of the eruption without warning, the initial description of the event as a storm, the zigzag-type lightening, the extremely loud continuous explosions, the ash fallout extending for hundreds of kilometers causing darkness, and the rendering of roads impassable.

Figure 29. The 1793 San Martín volcanic eruption estimated ash distribution

San Martín Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian, 2014; * Nelson and Gonzalez-Caver, 1992; **Jaime-Riverón and Pool, 2009; Santley 2007; ***Santley et al., 2000)

Start Date	Certainty	VEI	Evidence	Activity Area
80 BC–320 AD	Confirmed		Radiocarbon (uncorrected)	South flank (Cerro Puntiagudo)
450 BC–150 AD	Confirmed		Tephrochronology	South flank
*39 AD–410 AD			Radiocarbon	Carbon underneath Puntiagudo
**65 AD –398 AD			Radiocarbon	Tres Zapotes
**65 AD –398 AD			Radiocarbon	Bezuapan
***50 BC–750 AD	two sigma		Radiocarbon	Matacapan
***450 BC–550 AD	two sigma		Radiocarbon	Matacapan
***850 BC–900 AD	two sigma		Radiocarbon	Matacapan
***850 BC–350 AD	two sigma		Radiocarbon	Matacapan
***850 BC–350 AD	two sigma		Radiocarbon	Matacapan
***365 BC–55 AD	uncalibrated		Radiocarbon	Bezuapan
***80 AD–680 AD	one sigma		Radiocarbon	Bezuapan
***50 AD	Confirmed		Radiocarbon	La Joya

Maximum recent (3000 BC to present) historical known VEI for San Martín: 4

2. Pico de Orizaba

Pico de Orizaba, also known as Citlaltépetl ("Mountain of the Star"), is Mexico's highest volcano and North America's third highest peak. Figure 30 shows it from the south. The snow-free peak at the left is Sierra Negra, a 4580-m-high Pleistocene volcano that was active simultaneously with Orizaba. Historical eruptions have consisted of moderate explosive activity and the effusion of dacitic lava flows. The latest eruption occurred during the 19th century.

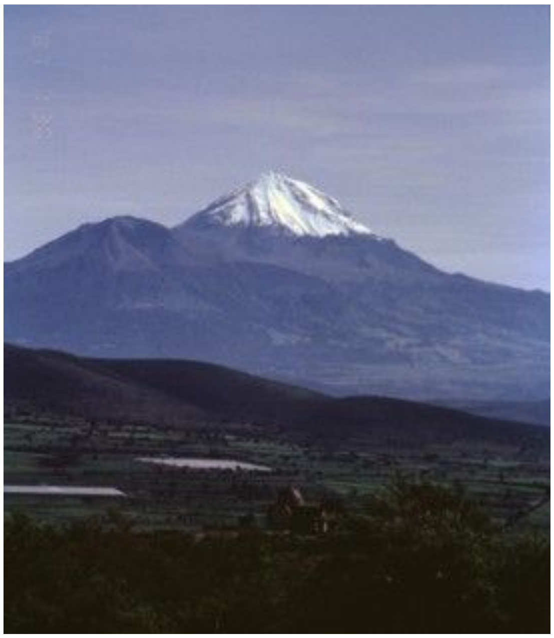


Figure 30. Pico de Orizaba

The last major eruption of Pico de Orizaba occurred around 2150 BC, and involved the explosive disruption of a lava dome in the summit crater, forming a succession of block and ash flow and lahar deposits on the southeast and west sectors of the volcano that extend up to about 28 km from the vent. Since the last major eruption, 8 different moderate pyroclastic flow eruptions have been identified, including ash flows, scoria flows, and block and ash flows. A pyroclastic eruption relative to the 3rd Nephi time frame shows up in the geologic record with dated samples from 40 AD ± 40 years and 90 AD ± 40 years in the Texmalaquilla area, about 8 kilometers from the cone. A tephra fall deposit associated with an explosive eruption was reported at 140 AD ± 50 years in the San Jose area.

The extent of the volcanic deposits related to the pyroclastic eruption appears to be limited to 10 to 12 kilometers from the volcano cone. This eruption was classified as 'minor' (Höskuldsson et al., 1993*)* and assigned a VEI of 3.

Pico de Orizaba Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian, 2014; Höskuldsson et al., 1993)

Start Date	**Certainty**	**VEI**	**Evidence**	**Activity Area**
140 ± 50 AD	Confirmed	3	Radiocarbon (uncorrected)	
90 ± 40 AD	Confirmed	3	Radiocarbon (uncorrected)	
40 ± 40 AD	Confirmed	3	Radiocarbon (uncorrected	

Maximum recent (3000 BC to present) historical known VEI for Pico de Orizaba: 4

3. Popocatépetl

Popocatépetl, whose Aztec name means "Smoking Mountain," is a massive stratovolcano that towers more than 3200 m above the Valley of Mexico and forms North America's 2nd-highest volcano. The glacier-clad stratovolcano contains a steep-walled, 400 x 600 m wide crater. The generally symmetrical volcano is modified by the sharp-peaked Ventorrillo on the northwest, a remnant of an earlier volcano. At least three previous major cones were destroyed by gravitational failure, producing massive debris-avalanche deposits covering broad areas to the south. Three major plinian eruptions, the most recent of which took place about 800 AD, have occurred from Popocatépetl since the mid-Holocene, accompanied by pyroclastic flows and voluminous lahars that swept basins below the volcano. Frequent historical eruptions, first recorded in Aztec codices, have occurred since pre-Columbian time.

Records of the eruptions of Popocatépetl extend back to Aztec records in 1354 AD and also include Spanish Colonial records (Cruz – Reyna et al. 1995). These records do not contain a thorough accounting of any eruption to the specificity provided in the 1793 San Martín volcano eruption. An eruption in 1592 indicated that ash distribution extended 8 leagues (45 km) to Puebla, Tlaxacata, and Chalco. The distance to Tlaxacata is on the order of 50 km, but it is clear the ash extended in all directions around the volcano.

Studies of the deposits of what geologists refer to as the 200 BC eruption indicate that it included pyroclastic surges that extended up to 20 kilometers, and also included lahar flows. There are indications that stratospheric transport of the ash in this eruption occurred eastward (Macías, 2007, 202). This eruption has been characterized by archeological excavations at Tetimpa as occurring in the late part of the first century AD based on radiocarbon dating from that archeological site (Plunket et al., 1998, 292). Evidence at the site indicates that inhabitants had to flee the volcanic eruption.

Figure 31. Popocatépetl Volcano, December 1994

Popocatépetl Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian, 2014; Macías, 2007; Plunket et al., 1998)

Start Date	**Certainty**	**VEI**	**Evidence**	**Activity Area**
AD 240 (AD 90–395)	2 sigma		Radiocarbon	Tetimpa
100 AD (20 BC–AD 245)	2 sigma		Radiocarbon	Tetimpa
80 AD (91 BC–AD 315)	2 sigma		Radiocarbon	Tetimpa
75 AD (45 BC–AD 225)	2 sigma		Radiocarbon	Tetimpa
50 BC (357 BC–AD 116)	2 sigma		Radiocarbon	Tetimpa
181 BC (390 BC–AD 20)	2 sigma		Radiocarbon	Tetimpa
250 AD	Confirmed		Radiocarbon (uncorrected)	
200 BC ± 300 years	Confirmed	4	Radiocarbon (uncorrected)	

Maximum recent (3000 BC to present) historical known VEI: 4

4. Other volcanoes in the land northward

The following volcanoes have been active since 3rd Nephi time frames, but no eruption has yet been found during the appropriate time frame. There may be some possibility that future research may identify eruptions with a suitable time frame:

- Cofre di Perote
- Chichinautzin (includes Xitle)
  Maximum recent (3000 BC to present) historical known VEI: 3

The following volcanoes have not been active since 3rd Nephi time frames, and for the most part have been inactive long before 3rd Nephi time frames. There is limited possibility that future research may identify eruptions with a suitable time frame:

- Naolinco Volcanic Field
- Los Atlixcos
- La Gloria
- Las Cumbres
- Serdan Oriental
- La Malinche
- Papayo
- Iztaccihuatl
- Nevado de Toluca
- Jocotitlán

Volcanoes in the Land Southward

The Sorenson model does not consider geography much beyond Lake Amatitlan, as that is the southern boundary of the Land of Nephi in that model. Volcanoes in the land southward are shown in figure 32 with the exception of El Chichón, which is shown in figure 22.

Figure 32. Southernmost volcanoes: red indicates active during 3rd Nephi time; pink indicates historically active but lacking data

1. El Chichón

El Chichón is a small, but powerful tuff cone and lava dome complex that occupies an isolated part of the Chiapas region in southeast Mexico, far from other active volcanoes. Prior to 1982, this relatively unknown volcano was heavily forested and of no greater height than adjacent non-volcanic peaks. The largest dome, the former summit of the volcano, was constructed within a summit crater created about 220,000 years ago. Two other large craters are located on the southwest and southeast flanks; a lava dome fills the southwest crater, and an older dome is located on the northwest flank. The powerful 1982 explosive eruptions of magma destroyed the summit lava dome and were accompanied by pyroclastic flows and surges that devastated an area extending about 8 km around the volcano. The eruptions created a new 1-km-wide, 300-m-deep crater that now contains an acidic crater lake (see figure 33). The El Chichón volcano, like the San Martín volcano, also occurs with a strike-slip fault cutting through it (see figure 34).

Figure 33. El Chichón, June 1982, two months after eruption

The volcanic deposits of El Chichón have been mapped with assignment of letters in alphabetical order going from the youngest to oldest deposits. The deposits of interest in relation to the 3rd Nephi time frame are the Tephra H and perhaps the Tephra G deposits. These deposits basically consist of pyroclastic flow surge deposits and ashfall. The extent of the ashfall distribution of the level VEI 5 1982 eruption is shown in figure 35 and extended over an area 425 kilometers wide.

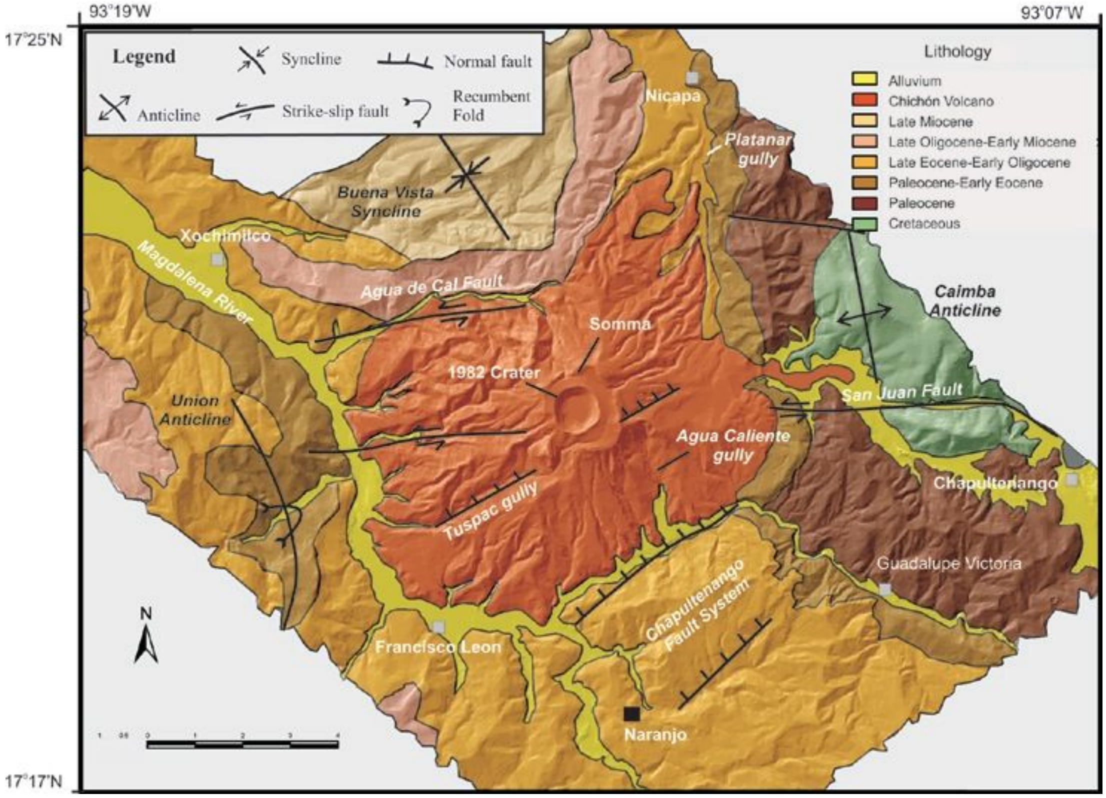


Figure 34. Geologic Map of El Chichón Volcano showing strike-slip fault through the volcano (Macias, 2007)

El Chichón Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian, 2014; Espíndola et al., 2000*; Nooren, 2009**)

Start Date	Certainty	VEI	Evidence	Activity Area
190 AD ± 150 years	Confirmed		Radiocarbon (corrected)	Tephra unit G
20 BC ± 50 years	Confirmed		Radiocarbon (corrected)	Tephra unit H
*BC 5 (BC 114–AD 76)	1 sigma		Radiocarbon	Tephra unit H
*BC 36 (BC 191–AD 86)	1 sigma		Radiocarbon	Tephra unit H
*BC 36 (BC 191–AD 104)	1 sigma		Radiocarbon	Tephra unit H
*BC 36 (BC 191–AD 112)	1 sigma		Radiocarbon	Tephra unit H
*AD 135 (AD 75–AD 240)	1 sigma		Radiocarbon	Tephra unit G
**30 BC (120 BC–60 AD)	1 sigma		Radiocarbon	Tephra unit H
**145 BC (140 BC–150 BC)	1 sigma		Radiocarbon	Tephra unit H
**AD 95 (AD 80–AD 110)	1 sigma		Radiocarbon	Tephra unit G

Maximum recent (3000 BC to present) historical known VEI: 5

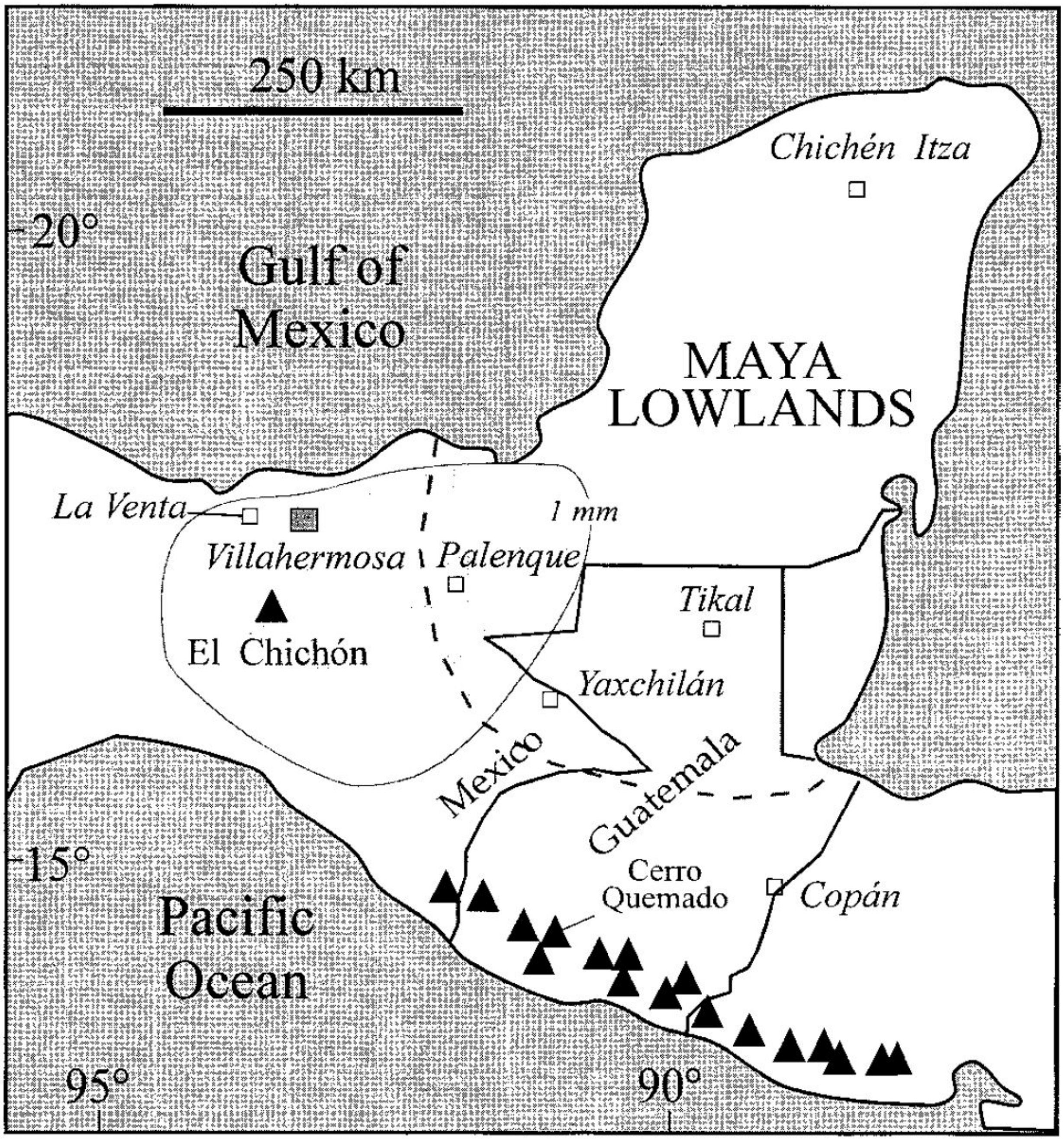


Figure 35. Map showing ashfall distribution from 1982 El Chichón eruption (Espíndola et al., 2000, 93)

2. Tacaná

Tacaná is a 4060-m-high composite stratovolcano that straddles the Mexico/Guatemala border at the Northwest end of the Central American volcanic belt (figure 36). Three large calderas breached to the south, and the elongated summit region is dominated by a series of lava domes intruded along a northeast-southwest trend. Volcanism has migrated to the southwest, and a small lava dome is located in the crater of the youngest volcano, San Antonio, on the upper southwest flank. Viscous lava flow complexes are found on the north and south flanks, and lahar deposits fill many valleys.

There is one eruption that is of interest to 3rd Nephi time frames. The eruption originated from the San Antonio volcano. This eruption produced an explosion that destroyed the summit dome, which generated pyroclastic surges and block-and-ash flow deposits that traveled 14 kilometers from the summit through ravines.

Figure 36. Tacaná Volcano, June 1986

Tacaná Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian, 2014)

Start Date	Certainty	VEI	Evidence	Activity Area
AD 70 ± 100 years	Confirmed	4	Radiocarbon (corrected)	San Antonio (upper SW flank)

Maximum recent (3000 BC to present) historical known VEI: 4

3. Acatenango

Acatenango (figure 37), along with its twin volcano to the south, Volcán Fuego, overlooks the historic former capital city of Antigua, Guatemala. The first well-documented eruptions of Acatenango took place from 1924 to 1927, although earlier historical eruptions may have occurred. Francisco Vasquez, writing in 1690, noted that in 1661 a volcano that lay aside of Fuego "opened a smoking mouth and still gives off smoke from another three, but without noise."

The one eruption that occurred within the 3rd Nephi time frame principally involved ashfall tephra deposits.

Figure 37. Acetenango Volcano

Acetenango Eruptive History during Potential 3rd Nephi Time Frames (Smithsonian 2014; Valance 2001)

Start Date	Certainty	VEI	Evidence	Activity Area
AD 90 ± 100 years	Confirmed		Radiocarbon (uncorrected)	Pico Central
AD 90 ± 90 years			Radiocarbon	Pico Mayor

Maximum recent (3000 BC to present) historical known VEI: 3

4. Other volcanoes in the land southward

The following volcanoes have been active since 3rd Nephi time frames, but no eruption has yet been found during the appropriate time frame. Care should be taken to make too many conclusions about the volcanoes listed in this section for the land southward, as very little specific research involving historical eruptions has occurred on most of these volcanoes. There may be some possibility that future research may identify eruptions with a suitable time frame for the following volcanoes:

- Tajumulco
- Santa Maria
- Almolonga
- Fuego
- Pacaya

- Tecuamburro
- Atitlán

Maximum recent (3000 BC to present) historical known VEI: 6

The following volcanoes have not been active since 3rd Nephi time frames, and for the most part have been inactive long before 3rd Nephi time frames; however, there is a lack of research on these volcanoes. There is limited possibility that future research may identify eruptions with a suitable time frame for the following volcanoes:

- Toliman
- Agua
- Cuilapa-Barbarena

Oil and Gas Provinces

There is one potential type of earthquake byproduct, mud volcanoes, which occur exclusively in oil and gas areas, so it is important to note the extent of those areas as shown in figure 38.

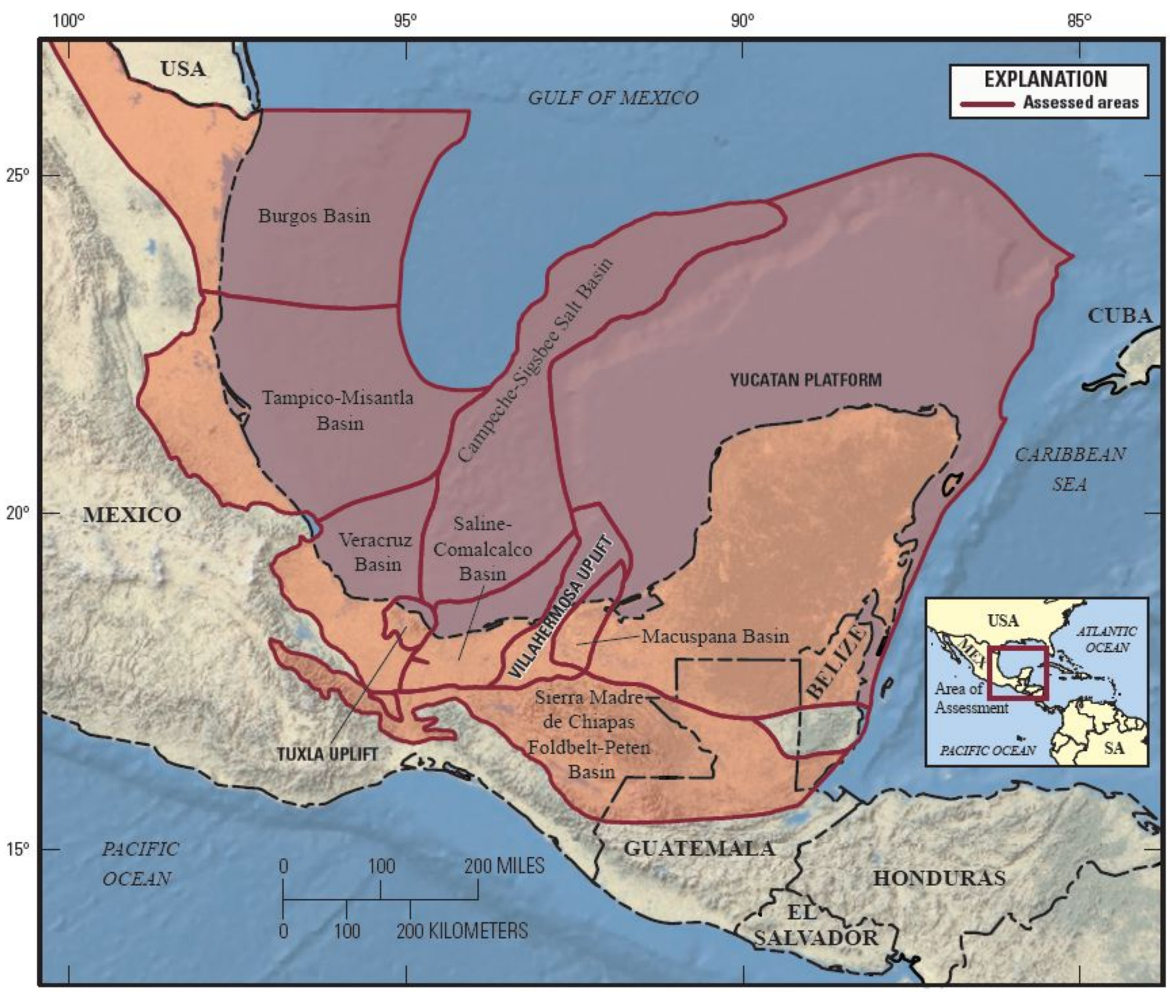


Figure 38. Existing and potential oil and gas provinces in the Isthmus of Tehuantepec (Schenk et al., 2012, 1)

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.

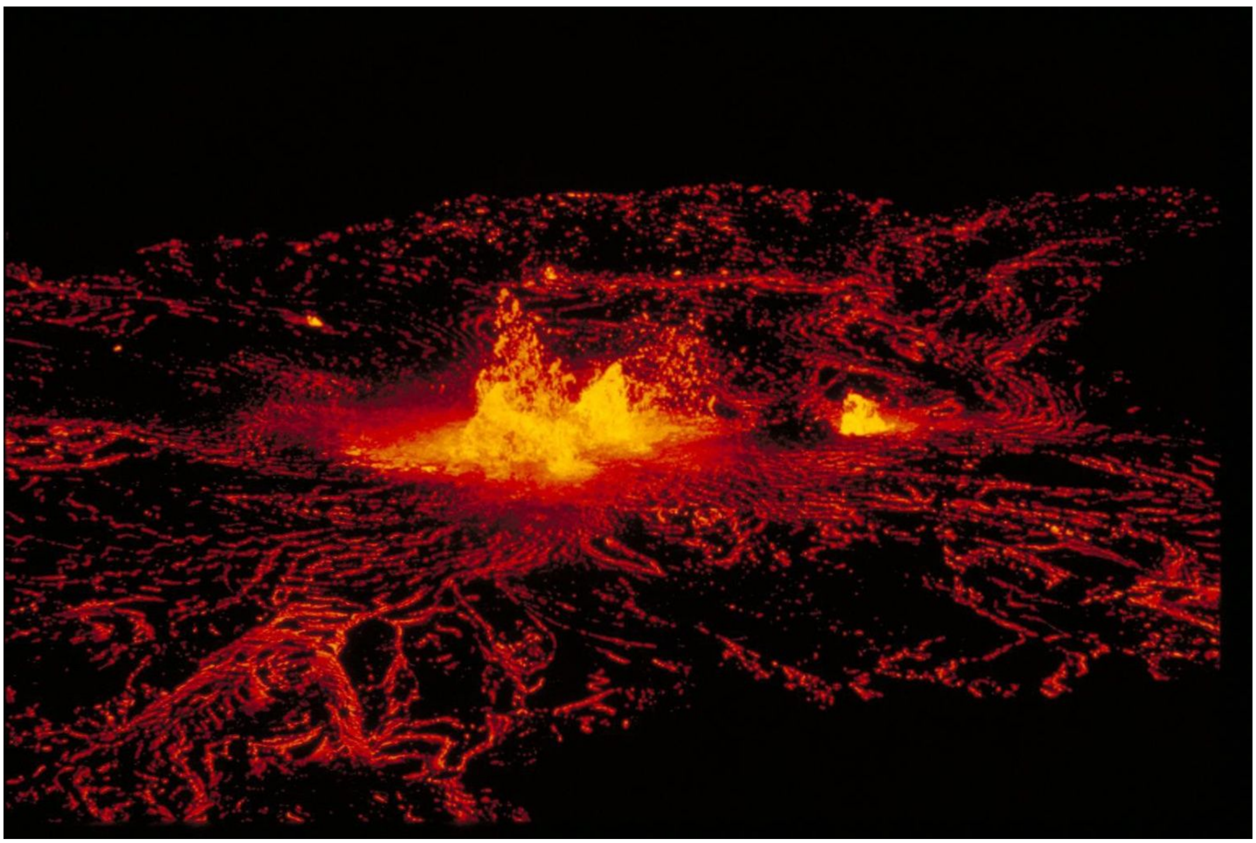


Figure 42. Lava at Hawaii Volcanoes National Park (courtesy US National Parks Service, 2014)

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).

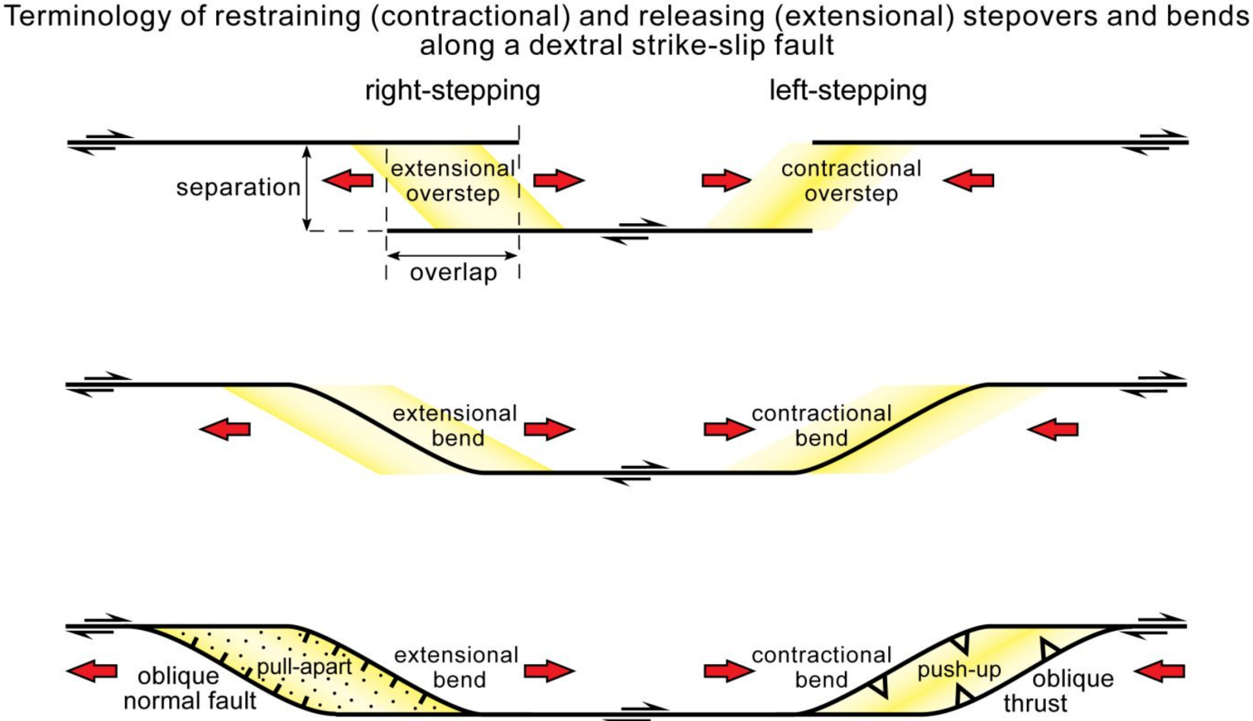


Figure 43. Diagram of subsidence and uplift zones along a strike-slip fault system (Berg, 2013)

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.

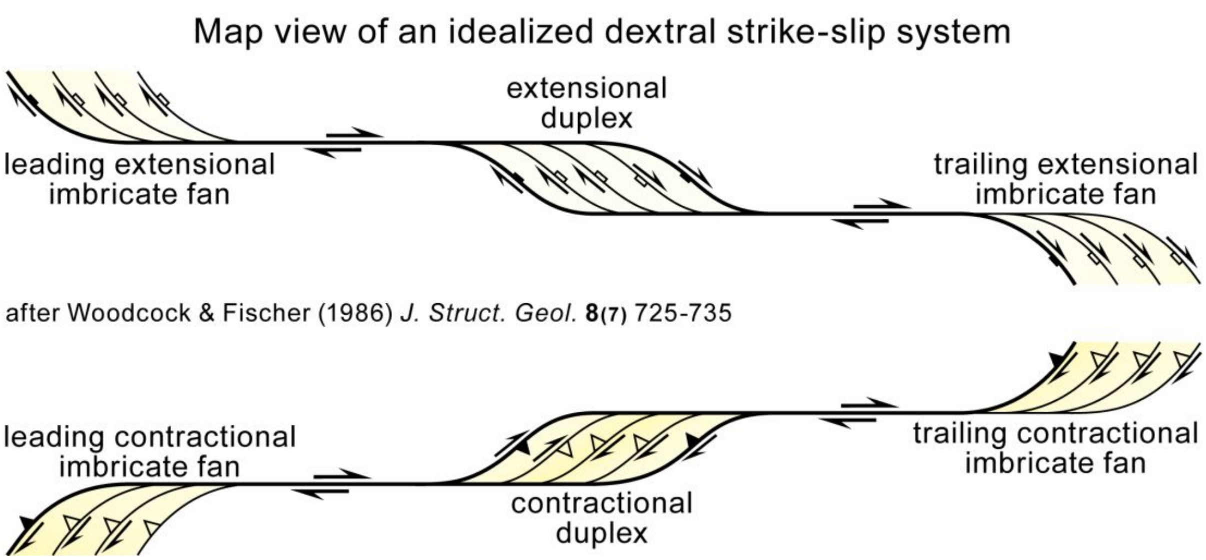


Figure 44. Complex fracture and rupture patterns in areas of subsidence and uplift in strike-slip fault system (Berg, 2013)

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).

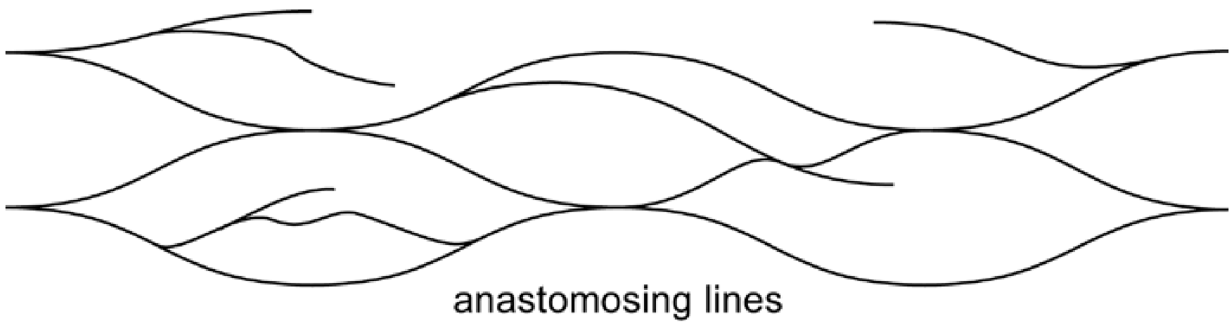


Figure 45. Braided pattern on strike-slip fault (Berg, 2013)

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).

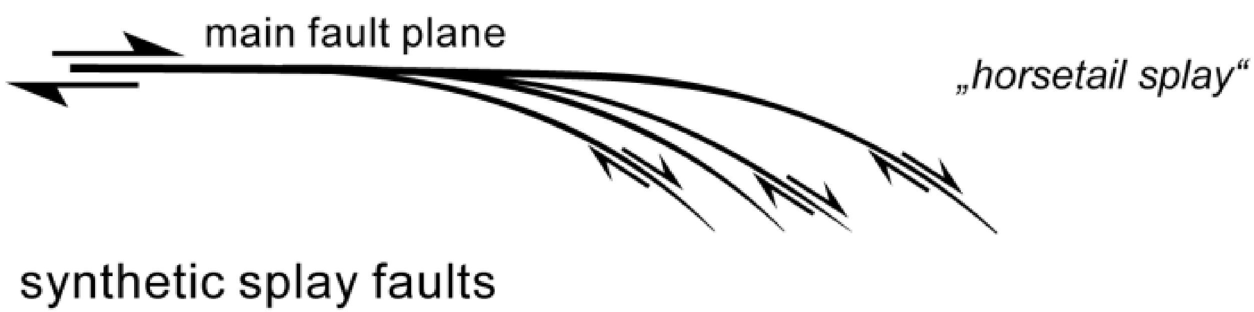


Figure 46. Splay fault and rupture pattern at the end of a strike-slip fault (Berg, 2013)

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).

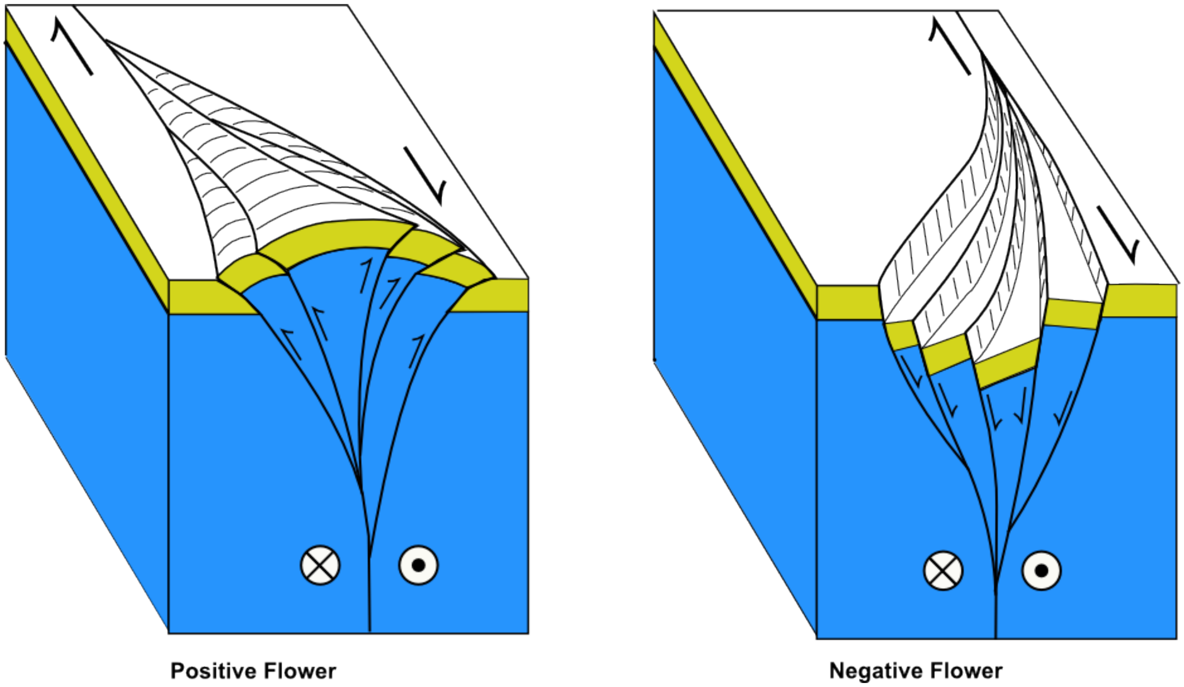


Figure 47. Flower structures of a strike-slip fault (courtesy Creative Commons, 2014)

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

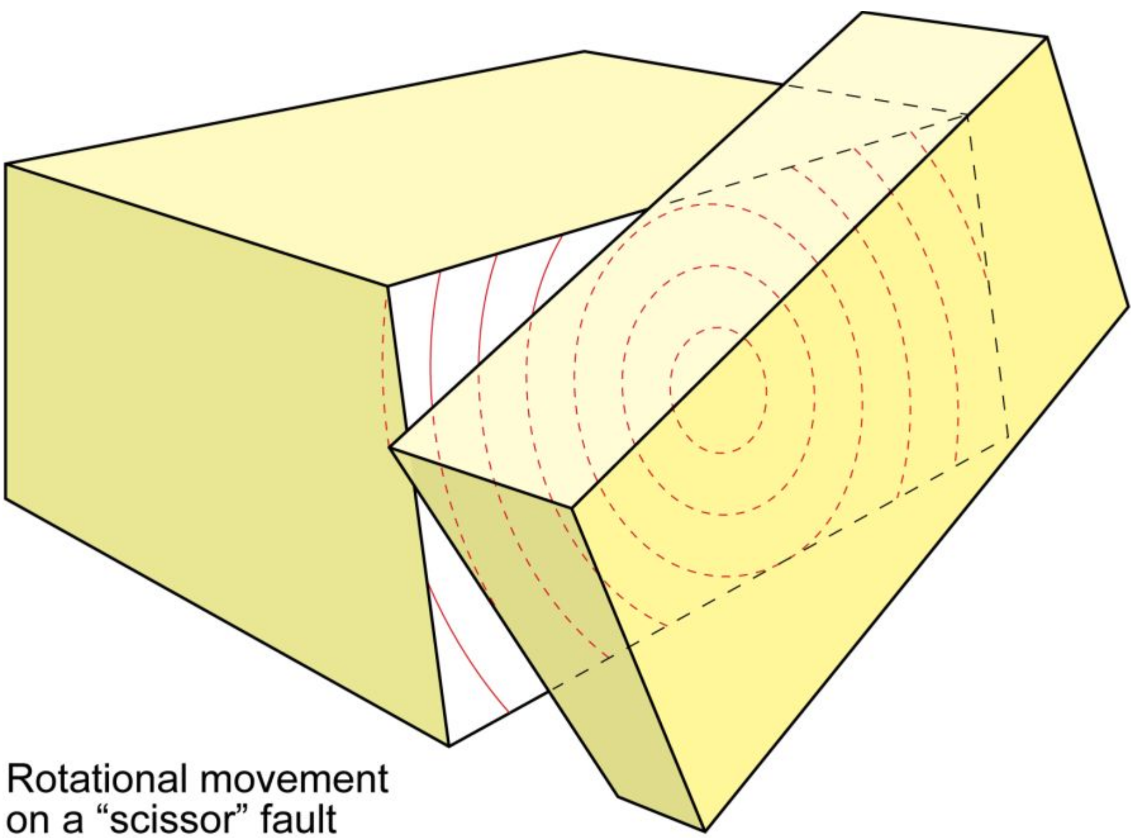


Figure 48. Strike-slip scissor fault movement (Berg, 2013)

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

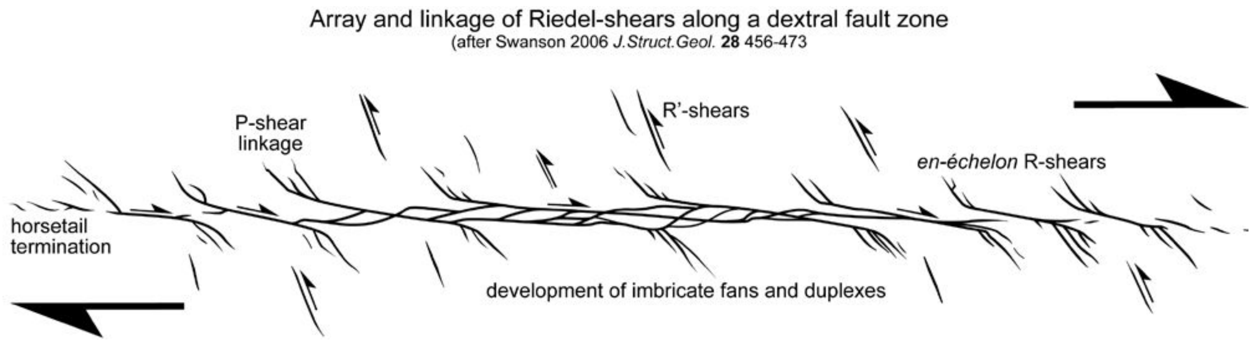


Figure 49. Typical shear faults along main strike-slip fault zone (Berg, 2013)

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

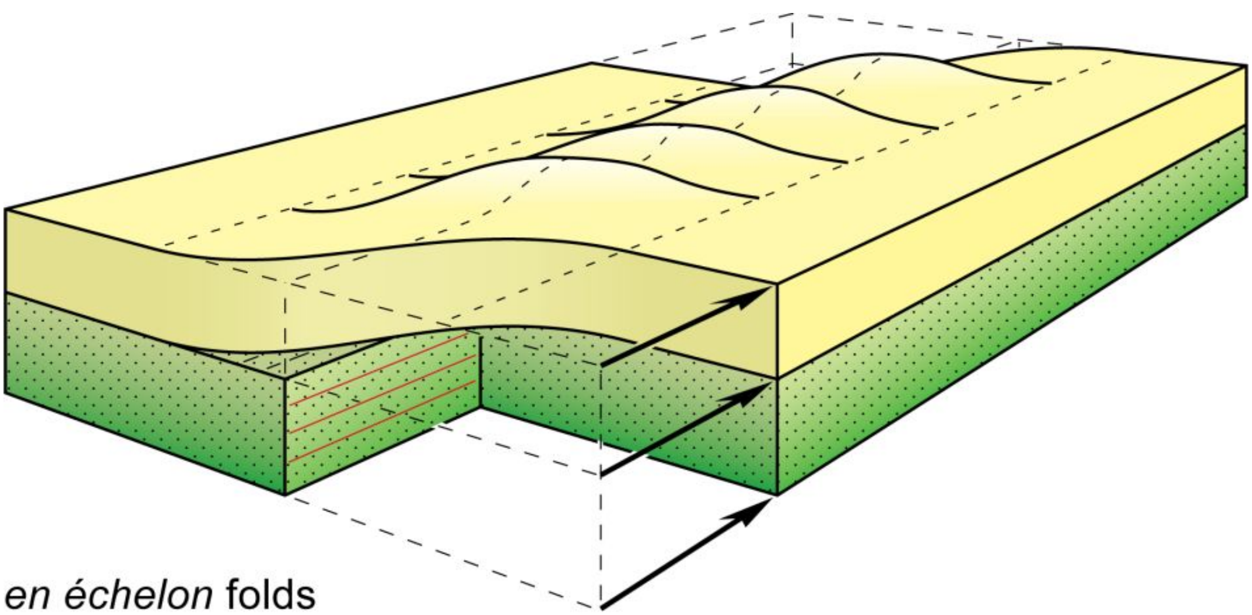


Figure 50. Strike-slip fault folding (Berg, 2013)

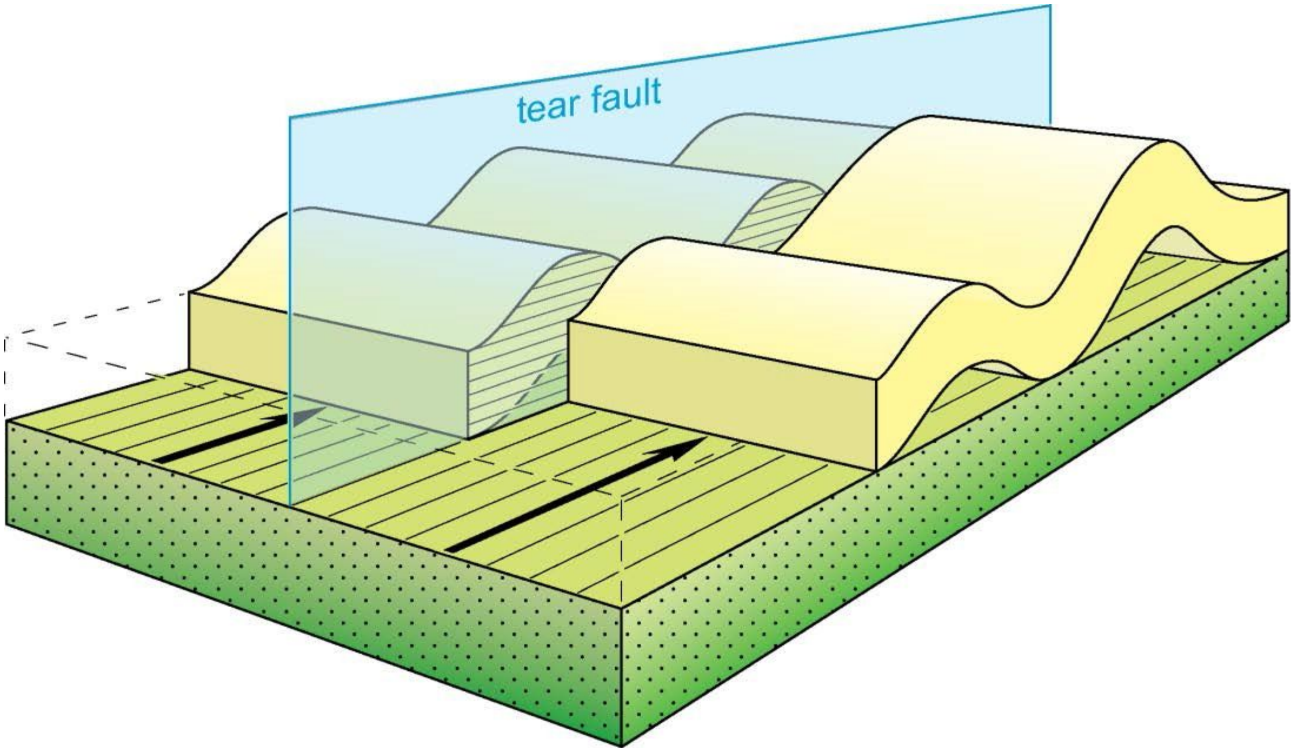


Figure 51. Strike-slip tear fault folding (Berg, 2013)

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.”

Chapter 5
Destruction Timeline

In evaluating the hazards mentioned as part of the 3rd Nephi catastrophe, some of them have dependency on time factors. Specifically, storm events need to be looked at in context of seasonality, and other hazards will have to be evaluated in terms of the time available for them to occur as identified in the text of the Book of Mormon.

Timeline Based on 3rd Nephi

3rd Nephi 8:5 states:

> And it came to pass in the thirty and fourth year, in the first month, on the fourth day of the month, there arose a great storm, such an one as never had been known in all the land.

One might assume on first reading that this date refers to January 4, 34 AD; however, the calendar system of the Nephites was recalibrated at or shortly after the birth of Christ, so using zero AD as a base date would not be accurate. In addition, we know that the catastrophe coincided with the death of Christ, which did not occur in January. The scope of this inquiry is not to discuss the various Mesoamerican calendrical systems or to discuss the methods of establishing the date of Christ's death using the Passover and other Old World correlations, but only to establish the time relationships necessary to interpret the hazards presented in 3rd Nephi.

Those that have compared the date for the crucifixion of Christ with Book of Mormon and Mesoamerican information have asserted it to be on the 14th day of the Jewish month Nisan. There still appears to be differences of opinions as to how this would equate to the Julian dates (the currently used calendar) with the remaining possibilities being March 16 or 18, 29 AD (Spackman, 1993, 68), or April 6 or 7, 30 AD (Chadwick, 2010). Sources that do not attempt to utilize Book of Mormon or Mesoamerican information have arrived at dates for the crucifixion of April 7, 30 AD, or April 3, 33 AD (Finegan, 1964, 300). For purposes of this inquiry, the range of years from 29 AD to 33 AD is not critical, as archaeological radiocarbon dating and other geologic dating techniques are not close to that range of accuracy. When dealing with seasonality of events, late March and early April will be the assumed range as to when the 3rd Nephi disaster started.

3rd Nephi 8:19 states:

> And it came to pass that when the thunderings, and the lightnings, and the storm, and the tempest, and the quakings of the earth did cease—for behold, they did last for about the space of three hours; and it was said by some that the time was greater; nevertheless, all these great and terrible things were done in about the space of three hours—and then behold, there was darkness upon the face of the land.

The verses between 3rd Nephi 8:5 and 8:19 do not state exactly when during these three hours each of these individual items started other than indicating that the thunderings and the quakings were happening at the same time. As a group, they "lasted" and "were done" in about 3 hours, perhaps a little longer depending on the location. It seems to be clear from the language in verse 19 that the quaking of the earth was not one continuous quake, as the word "quaking" is used in the plural. The same can be said for the thunderings and the lightnings. This is an important distinction, especially with regards to the quaking and known earthquake phenomena.

It has been noted that the author in 3rd Nephi describing the disaster was no doubt relying on others for information as to what occurred at each geographical location (Kowallis, 1997, 142). Whether each of the persons providing the report from their area would have noted the specific number of earthquakes/aftershocks is not known, but would probably not be expected.

As with other ancient measurements of time, the term hour is not necessarily a standard unit of time. The word "hour" does not even appear in the Bible until the book of Daniel, and the word "hour" in the New Testament can mean anything from an instant, to 45 minutes, to an hour and a quarter, a period or three hours, or even longer (Potter, 1941). That there may be different measurements in Mesoamerica for the term hour is evidenced in Alma 18:14, where it indicates that the "king answered him not for the space of an hour *according to their time*" (emphasis added). Although the length of an hour is not necessarily critical to this hazard analysis, a longer hour may provide for a longer length of time for the hazards that are delimited to the three-hour period identified in 3rd Nephi.

After the period of three hours, darkness commenced on the land and lasted for three days:

3rd Nephi 8:23 states:

> And it came to pass that it did last for the space of three days that there was no light seen; and there was great mourning and howling and weeping among all the people continually; yea, great were the groanings of the people, because of the darkness and the great destruction which had come upon them.

Sometime during the time of darkness, the voice of Jesus Christ spoke and identified the specific destruction of each of the sixteen cities that had already occurred (3rd Nephi 9:3–12). After the voice of Jesus Christ spoke there was another period of time that passed, "the space of many hours."

3rd Nephi 10:1–2 states:

> And now behold, it came to pass that all the people of the land did hear these sayings, and did witness of it. And after these sayings there was silence in the land for the space of many hours; or so great was the astonishment of the people that they did cease lamenting and howling for the loss of their kindred which had been slain; therefore there was silence in all the land for the space of many hours.

Following the "space of many hours" the voice of Jesus Christ spoke again, and then the darkness was dispersed. At the same time, certain of the natural occurrences also ceased, specifically the trembling of the earth, the rending of rocks, the dreadful groanings, and tumultuous noises. This is important to note, since the previous statements in 3rd Nephi regarding the storm, the thunderings, the lightenings, the tempest and the quakings having ended after three hours did not include all of what was still going on. Apparently earth tremblings, groanings, rendings, and tumultuous noises were occurring with some regularity during the three-day period of darkness, well beyond the initial three hours of destructive forces.

3rd Nephi 10:9 states:

> And it came to pass that thus did the three days pass away. And it was in the morning, and the darkness dispersed from off the face of the land, and the earth did cease to tremble, and the rocks did cease to rend, and the dreadful groanings did cease, and all the tumultuous noises did pass away.

Additional Timeline Information from Vision, Prophecies, and Angelic Description

While not necessarily what would be considered a first-hand source of direct observation, similar to the voice and recitation of the destruction by Jesus Christ in 3rd Nephi, if one believes in the veracity of the Book of Mormon as an inspired document, than the visions, prophecies, voice of Christ, and angelic descriptions of the future events must be evaluated and accounted for. It must of course be recognized that visions, prophecies, and descriptions of future events may not be recited, seen, or recounted in chronological order (as some may be concurrent), so care must be taken not to imply anything from the order of recitation or vision unless there is indication in the text of a time frame associated with a specific event. It is possible that some of the recounting may not even be in the order originally received, just as any recounting of concurrent events may perhaps change in order based on the purpose and intent of the recounting.

1. Nephi's Vision

In Nephi's vision as indicated in 1 Nephi 12:3–5 he recited the items in this order:

a) Mist of Darkness
b) Lightnings
c) Thunderings
d) Earthquakes
e) All manner of tumultuous noises
f) Earth and rocks rent
g) Mountains tumbling to pieces
h) Plains of the earth broken up
i) Cities that were sunk
j) Many (cities) that were burned with fire
k) Many (cities) tumble to the earth because of quaking

Nephi then recounts that after seeing these things, he saw the "vapor of darkness" that it passed from off the face of the earth.

2. Zenos' Prophecy

In the prophecy of Zenos as recited by Nephi in 1 Nephi 19:10–12 he recited the items in this order:

a) Three days of darkness would occur
b) Thunderings and lightnings
c) Tempest
d) Fire
e) Smoke
f) Vapor of darkness
g) Opening of the earth
h) Mountains which shall be carried up
i) Rocks of the earth must rend
j) Groanings of the earth

3. Samuel the Lamanite

Samuel the Lamanite's recounting of information from an angelic visit as recited to him in Helaman 14:20–29 included the following items:

a) In "the time" that Christ dies, the sun, moon and stars shall be darkened with no light, continuing for the "space of three days" until he shall rise from the dead
b) At "the time" Christ dies, for the "space of many hours" afterwards he recited that the following items would happen in this order:

- i) Thunderings and lightnings
- ii) Earth shall shake and tremble
- iii) Rocks above and below the face of the earth broken up
- iv) Rock(s) rent in twain and found in seams, cracks and broken fragments above and below the earth
- v) Great tempests
- vi) Many mountains made low like unto a valley
- vii) Many places called valleys which shall become mountains with great height
- viii) Many highways broken up and cities become desolate

Summary

Based on all of this information a summary of the 3rd Nephi timeline would be as follows:

- Christ dies on March 16 or 18, 29 AD; or April 6 or 7, 30 AD; or April 3, 33 AD.
- Immediately thereafter a great storm arose along with other destructive forces that lasted for roughly three "hours." Some of the destructive forces occurred intermittently throughout the three hours, others continuously.
- After the storm and other destructive forces ceased there was darkness "upon the face of the land" for three days.
- "Many hours" before the end of the three days, a summary of the destruction of the various cities was provided by the voice of Jesus Christ.
- During the three day period of darkness some continuing natural events were ongoing, namely, trembling of the earth, rending of rocks, dreadful groanings, and tumultuous noises.

The only apparent internal discrepancies in the timeline are that Nephi in his vision appears to have seen the mist of darkness prior to the destructive forces, instead of the mist of darkness occurring after the destructive forces. Since it is a vision, and considering that the destructive events would have been difficult to see when there was a mist of darkness, it would seem logical that there is no time or chronological relationship implied.

Samuel the Lamanite's recounting reference of the initiation of darkness "at the time" of Christ's death appears not to be a second-by-second recounting, but is a somewhat broader reference that can accommodate the 3rd Nephi recounting that the darkness started within 3 hours of the beginning of the destruction.

Chapter 6

Volcano-Only Scenario

In order to begin correlating 3rd Nephi events to locations on the ground, there are three potential primary hazards to consider that will drive all of the secondary hazards and damage: (1) volcanic activity, (2) earthquake activity, and (3) large storm/hurricane.

At the outset, in evaluating all of the events described in 3rd Nephi it is apparent that a volcano is an essential element, as there is really no other reasonable explanation for the mist and vapor of darkness that was widespread in the land northward and the land southward.

Most serious previous inquiries have included volcanic activity as a necessary element. However, it has been proposed in one of the more extensive inquiries that a volcano could explain *all* of the hazard types and damage elements (Kowallis, 1997, 142). This argument is based on the premise that volcanic activity can exclude the necessity of considering the addition of non-volcanic earthquakes and non-volcanic storm events. This premise will be examined in this chapter as we consider geophysical analysis in conjunction with the actual description of destruction described in 3rd Nephi. It will also be compared with the actual geology of the Isthmus of Tehuantepec to determine if the premise is valid.

Volcanic Earthquakes

As has been briefly mentioned in chapter 4, volcanoes typically generate earthquakes. However, 3rd Nephi does not contemplate just any magnitude of earthquake, it requires an earthquake of sufficient size to cause the “plains of the earth to be broken up” and cities to” tumble to the earth,” with “many great and notable cities sunk” and “shaken till the buildings thereof had fallen to the earth and the inhabitants slain” while leaving the remaining cities with exceedingly great damage.

Volcanic eruptions have been associated with earthquakes anciently. Pliny the Younger wrote of numerous earthquakes when he described the eruption of Vesuvius in 79 AD. Increase of earthquake activity before an eruption is caused by magma and volcanic gas forcing their way up through shallow underground fractures and passageways. This movement will either cause rocks to break or cracks to vibrate, triggering high frequency earthquakes. Most volcanic-related earthquakes are less than a magnitude 2 or 3 and occur less than 10 km beneath a volcano. The earthquakes tend to occur in swarms consisting of dozens to hundreds of events.

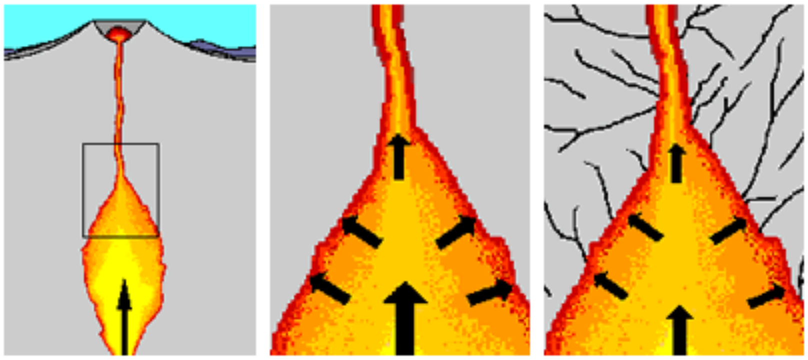


Figure 55. Volcanic earthquake propagation (USGS, 2014)

Scientists have been studying the seismic characteristics of volcanic earthquakes since the early 1900s. They have identified four types of earthquakes associated with a volcanic eruption (Zobin, 2003, 134–35, 192–93).

A-type. Earthquakes that originate from the base of a volcano, with typical depths of 1 to 20 km. They take place in swarms previous to and in the first stage of the eruption. They are generally less than a 6 in magnitude.

B-type. Earthquakes that are within 1 km of the radius of the active crater. These also take place in swarms and occur at a shallower depth than A-type earthquakes. Their magnitudes are typically extremely small.

Explosion earthquake. These are earthquakes that accompany the explosive eruption. The center is located beneath the active crater floor. The amplitude of the earthquake is dependent on the amplitude of the explosive eruption. The initial motion is not directed but pushes in all directions. Explosion earthquakes may occur as a single event or as long sequences.

Volcanic pulsation or continuous volcanic microtremors. The main part of these earthquakes are surface waves, the earthquakes being of a small amplitude.

Recent monitoring of volcanic eruptions has recorded the maximum amplitude of the volcanic earthquakes during eruptions. For example, three volcanic eruptions rated with a Volcanic Explosive Index (VEI) of 5 did not generate explosion earthquakes above 5.4 (M_w) in magnitude (Zobin, 2003). The volcano El Chichón, which has had one of the largest recorded eruptions in 1982 in what would be considered part of or near to the Book of Mormon land southward, did not even reach above an earthquake magnitude of 4:

Volcano	Earthquake Range of Magnitude (M_w)
El Chichón, Mexico, 1982	0-4.0
Bezymianny, Kamchatka, Russia, 1955–56	0-5.2
Mount St. Helens, United States, 1980	0-5.4

Volcanic earthquakes of any tectonic significance are extremely rare. There have been only three volcanic earthquakes with a magnitude of 7 (M_w) measured anywhere on earth in the past century (Zobin, 2001). These volcanoes were ones that had laid dormant for thousands of years and then suddenly erupted, not a known scenario for any of the volcanoes in lands related to the Book of

Mormon. The famous 1991 Mt. Pinatubo eruption, of which many are aware, only exhibited an earthquake of 5.6 (M_w).

Volcanic earthquakes behave differently than standard tectonic earthquakes (i.e., non directional, single point of explosion, not a movement of large sections of the earth's crust along a long fracture) so actual historical measurements have been utilized to develop predictions for volcanic eruptions. As previously discussed, there are different scales of measuring earthquakes, the M_w scale being based on seismic data. In order to convert this scale to the Modified Mercalli (MM) intensity scale and apply the historical data to a distance from a volcano, an equation was developed using historical volcanic earthquake data by Vyacheslav M. Zobin in 2003:

$$I = 0.66M_w – 1.13LogR – 0.0072R + 3.73$$

I: Intensity in Modified Mercalli

R: the distance away from the hypocentral point of the earthquake (the point on the surface immediately above the earthquake epicenter).

M_w: Intensity in Moment Magnitude Scale

Assuming the maximum volcanic earthquake measured, 7.1 M_w, and assuming that the earthquake is centered at the base of the volcano under the crater, then a distance can be calculated away from the volcano within which one might expect the type of damage described in the Book of Mormon. Table 3 shows the Modified Mercalli (MM) scale and related earthquake damage. The building and earth rupture damage described in the Book of Mormon would be at least an VIII on the Mercalli scale.

Table 3. Modified Mercalli Intensity Damage Scale

I. Instrumental	Generally not felt by people unless in favorable conditions.
II. Weak	Felt only by a couple of people who are sensitive, especially on the upper floors of buildings. Delicately suspended objects (including chandeliers) may swing slightly.
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration similar to the passing of a truck. Duration can be estimated. Indoor objects (including chandeliers) may shake.
IV. Moderate	Felt indoors by many to all people, and outdoors by few people. Some awakened. Dishes, windows, and doors disturbed, and walls make cracking sounds. Chandeliers and indoor objects shake noticeably. The sensation is more like a heavy truck striking building. Standing automobiles rock noticeably. Dishes and windows rattle alarmingly. Damage none.

V. Rather Strong	Felt inside and outside by most or all. Dishes and windows may break and bells will ring. Vibrations are more like a large train passing close to a house. Possible slight damage to buildings. Liquids may spill out of glasses or open containers. None to a few people are frightened and run outdoors.
VI. Strong	Felt by everyone, outside or inside; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight to moderate to poorly designed buildings, all others receive none to slight damage.
VII. Very Strong	Difficult to stand. Furniture broken. Damage light in building of good design and construction; slight to moderate in ordinarily built structures; considerable damage in poorly built or badly designed structures; some chimneys broken or heavily damaged. Noticed by people driving automobiles. Small landslides.
VIII. Destructive	Damage slight in structures of good design, considerable in normal buildings with a possible partial collapse. Damage great in poorly built structures. Brick buildings easily receive moderate to extremely heavy damage. Possible fall of chimneys, factory stacks, columns, monuments, walls, etc. Heavy furniture moved. Large landslides.
IX. Violent	General panic. Damage slight to moderate (possibly heavy) in well-designed structures. Well-designed structures thrown out of plumb. Damage moderate to great in substantial buildings, with a possible partial collapse. Some buildings may be shifted off foundations. Walls can fall down or collapse.
X. Intense	Many well-built structures destroyed, collapsed, or moderately to severely damaged. Most other structures destroyed, possibly shifted off foundation.
XI. Extreme	Few, if any structures remain standing. Numerous landslides, cracks and deformation of the ground.
XII. Catastrophic	Total destruction – everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. Even the routes of rivers can be changed.

When applying the equation to a 7.1 M_w earthquake, which is the biggest observed in a century, Level VIII earthquake damage occurs from the center of the volcano to a distance of 2.3 kilometers. A lower Level VII damage level occurs from 2.3 kilometers to 15 kilometers away from the volcano. It is clear that volcanic earthquake damage is very much limited to the proximity of the volcano itself. For most volcanoes, the range for significant volcanic earthquake damage is much less than the expected extent of lava or pyroclastic flows.

Even assuming that volcanic earthquakes were equivalent to tectonic earthquakes, because of the variable conditions of earthquake epicenter depth, soil, rock, and topography, all of which can accentuate, deflect, or diminish the damage potential of a given earthquake, it is useful to try to analyze the results of actual earthquakes in the area of geographic interest, which in this case is the area of the Isthmus of Tehuantepec.

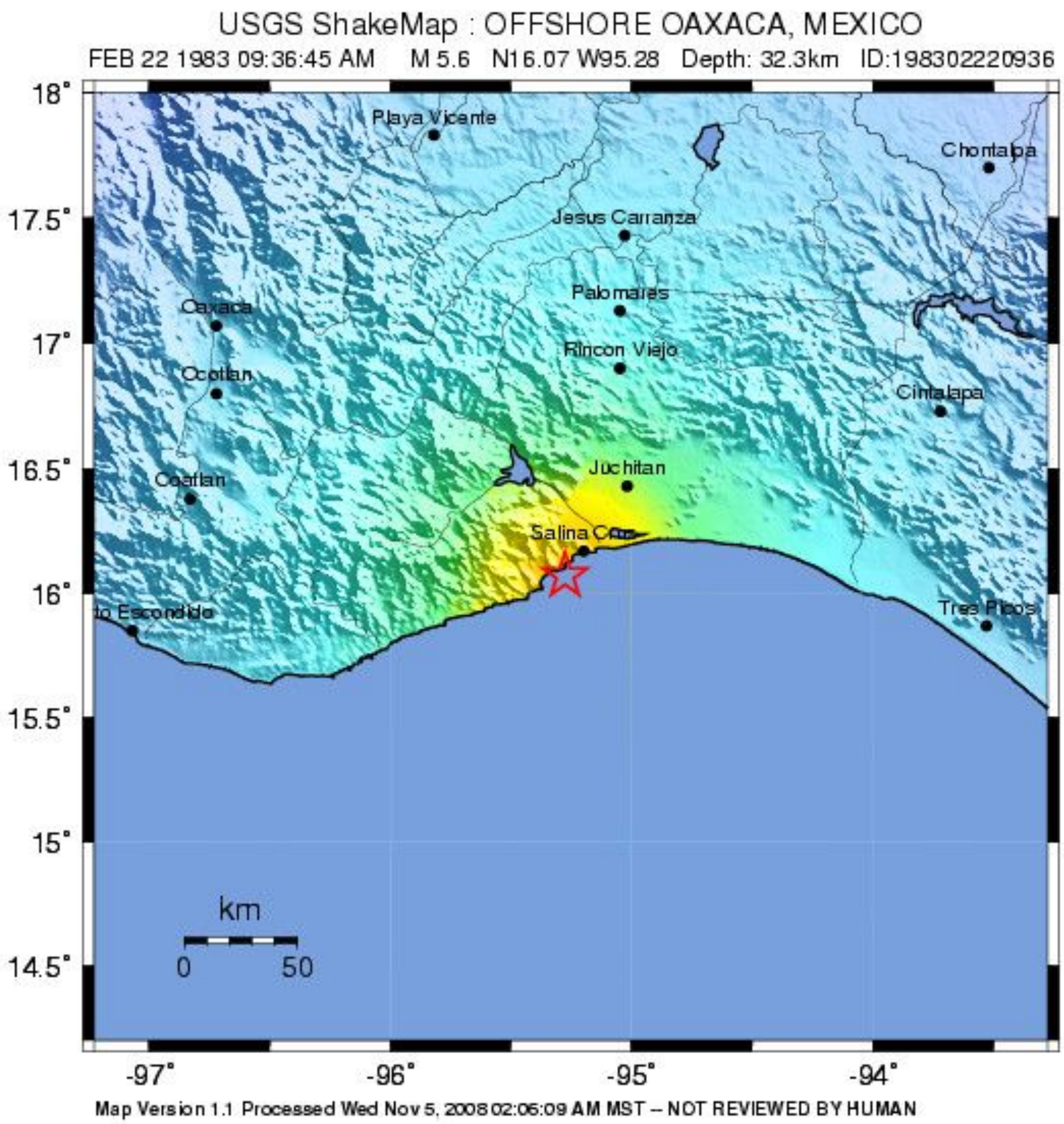
For some time, the United States Geological Survey, in conjunction with other countries, has developed "Shakemaps" that are derived from actual earthquake data. A ShakeMap is a representation of ground shaking produced by an earthquake. The information it presents is different from the earthquake magnitude and epicenter that are released after an earthquake because ShakeMap focuses on the ground shaking produced by the earthquake, rather than the parameters describing the earthquake source. So, while an earthquake has one magnitude and one epicenter, it produces a range of ground shaking levels at sites throughout the region depending on distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth's crust.

Included are all of the available Shakemaps for the Isthmus of Tehuantepec by nominal order of magnitude and within each magnitude by date. Shakemaps are not included for earthquakes below a magnitude of 5 M_w, hence the 1982 eruption of El Chichón is not included. Also included is the Shakemap for the destructive earthquake that occurred in 1985 in Mexico City, which shows that in unique soil and ground structure situations, some earthquakes can be severely amplified at a distance. In the case of Mexico City, because it was built on a filled-in lake that also has ground structure that creates harmonic amplitude in earthquake waves, an earthquake that caused virtually no damage between it and Mexico City, ended up being very destructive when the waves arrived at Mexico City.

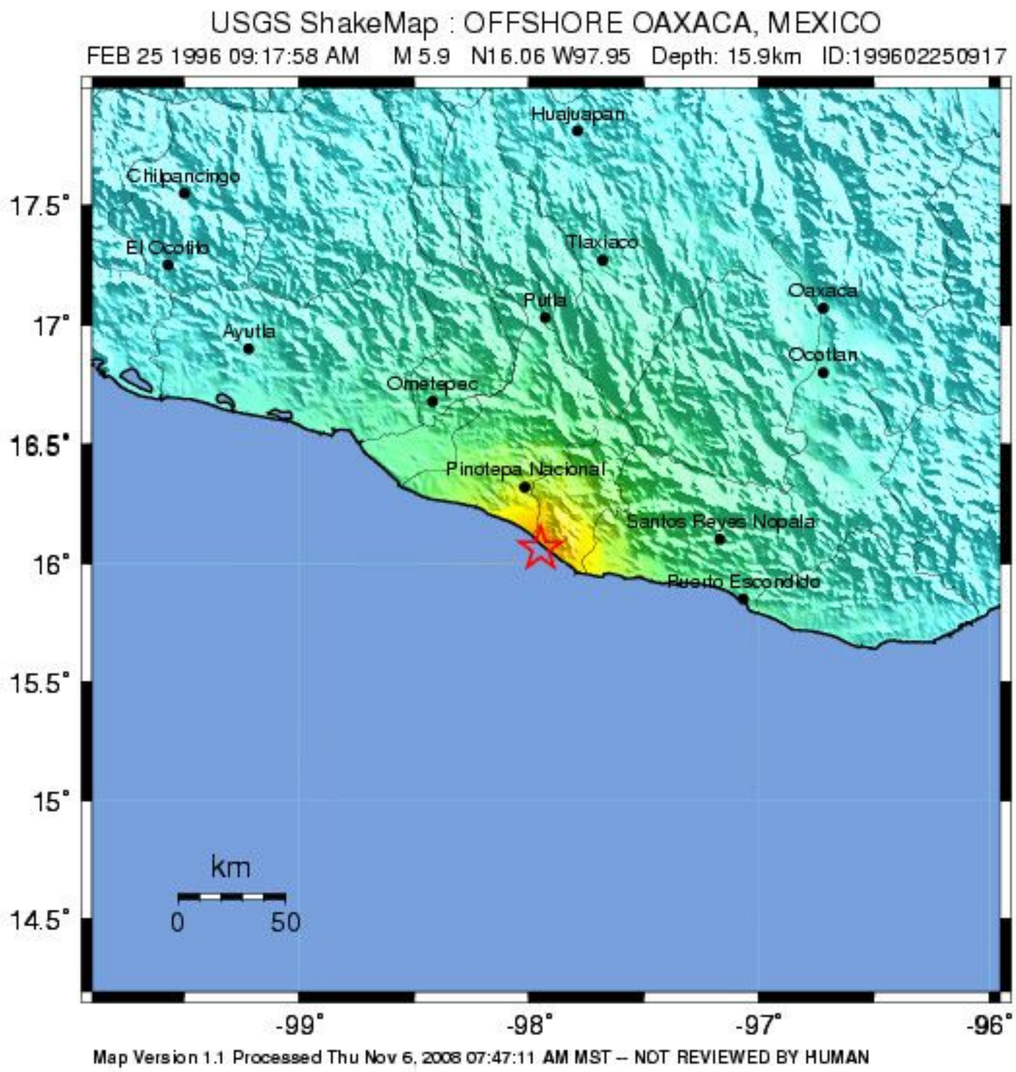
Please note that the Shakemap uses the letter "M" instead of "M_w"; these are abbreviations for the same thing in seismic abbreviation schemes. Also note that the color coding on each Shakemap denotes orange for a damage of Level VIII; the damage described in the Book of Mormon is a Level VIII or higher.

Figure 56. Shakemap Series

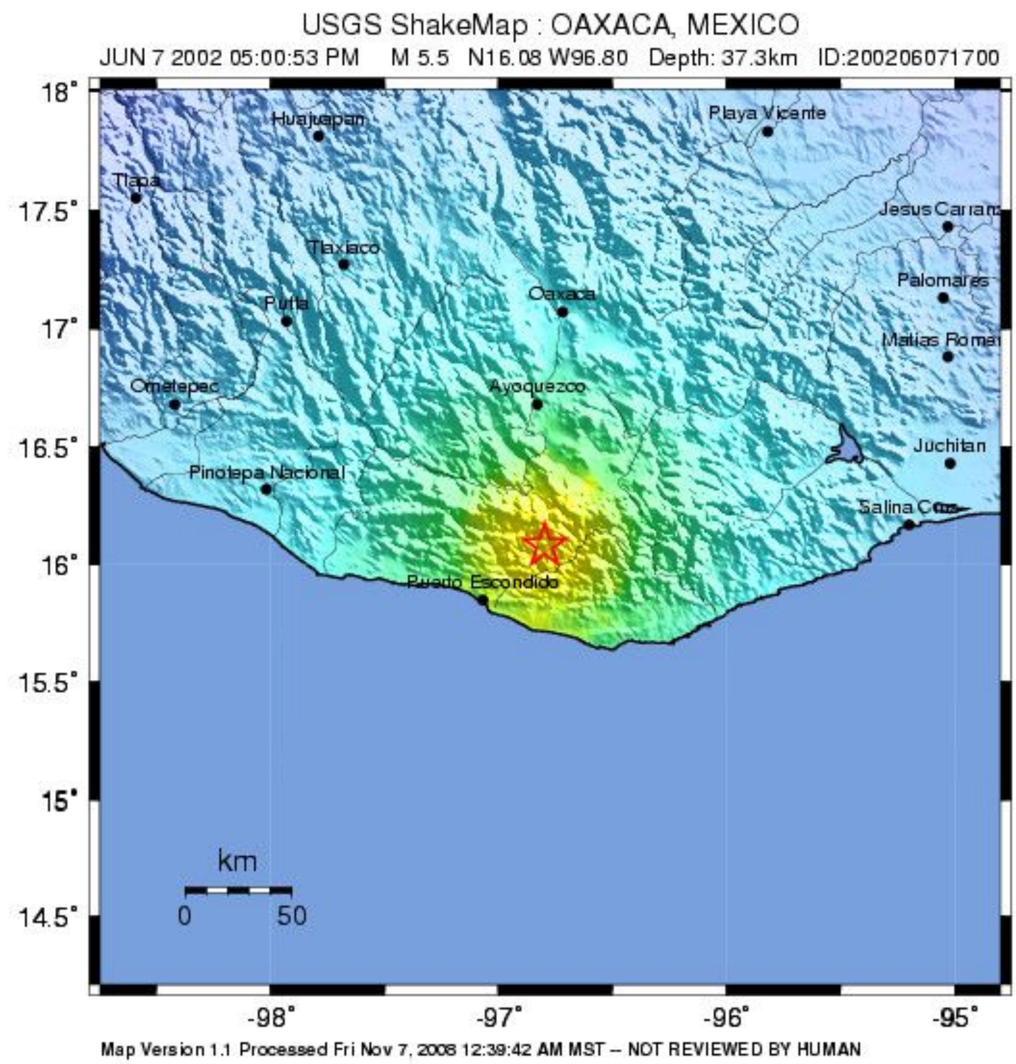
M_w 5 to 6 Earthquakes



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
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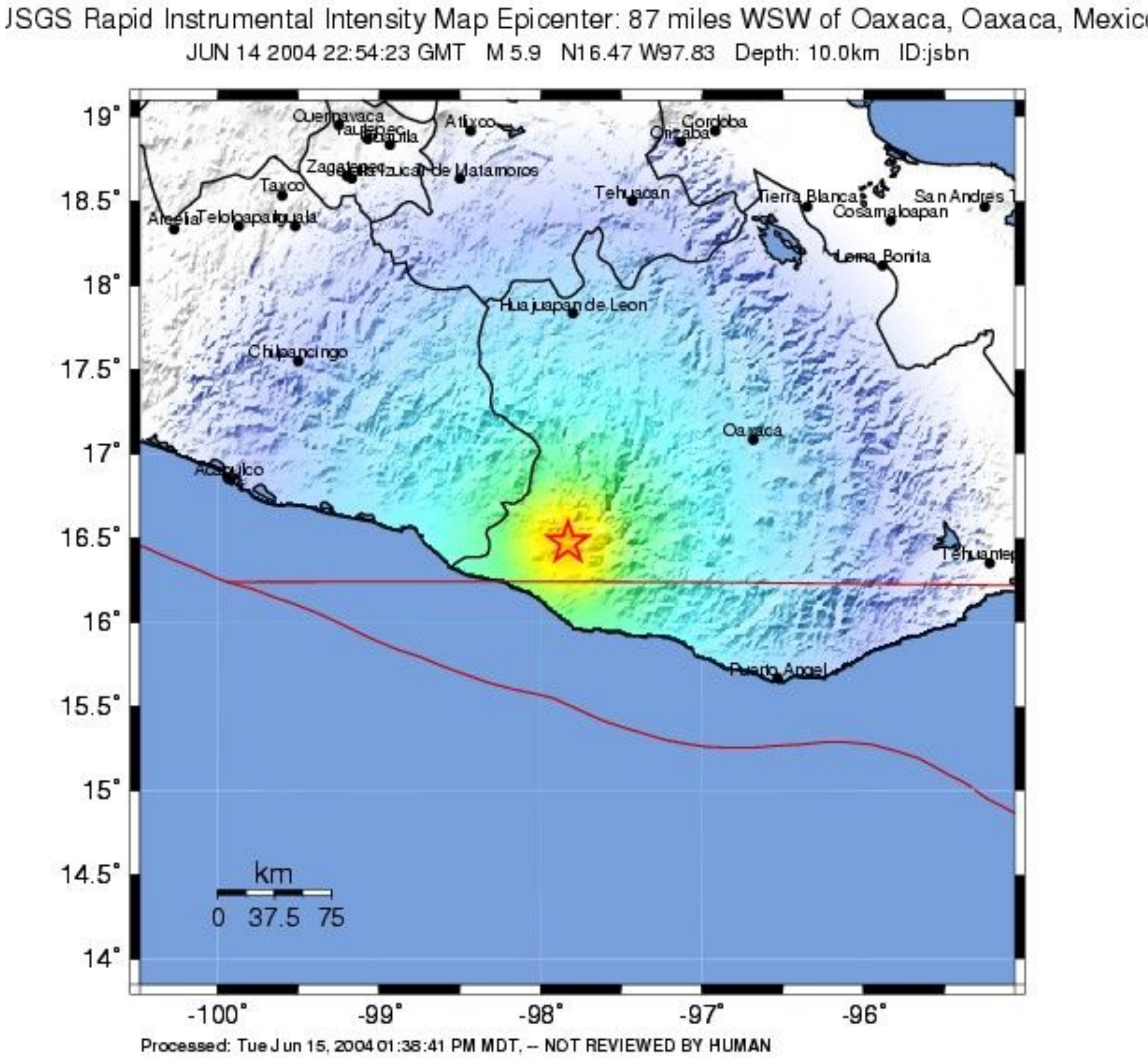
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
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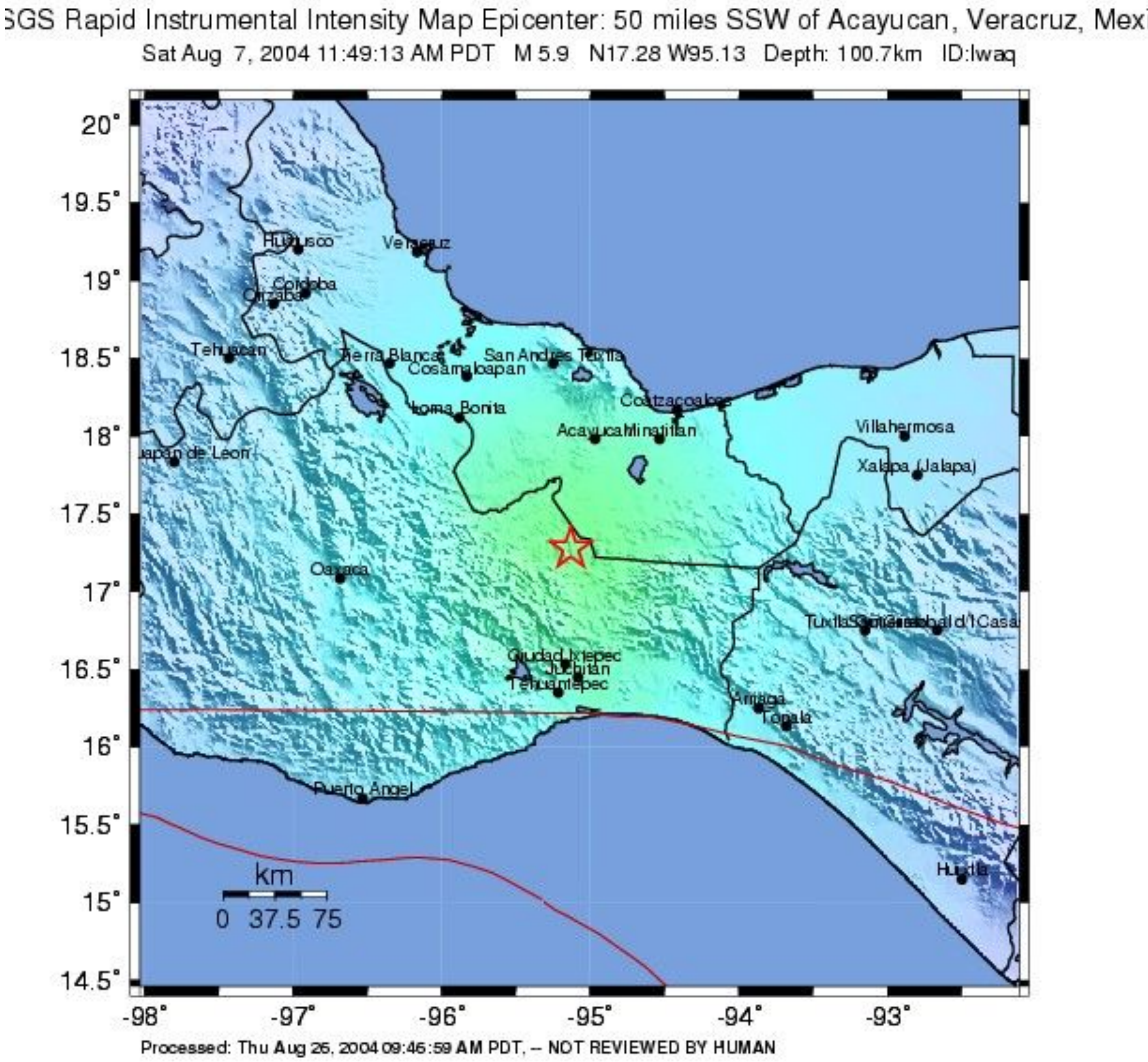

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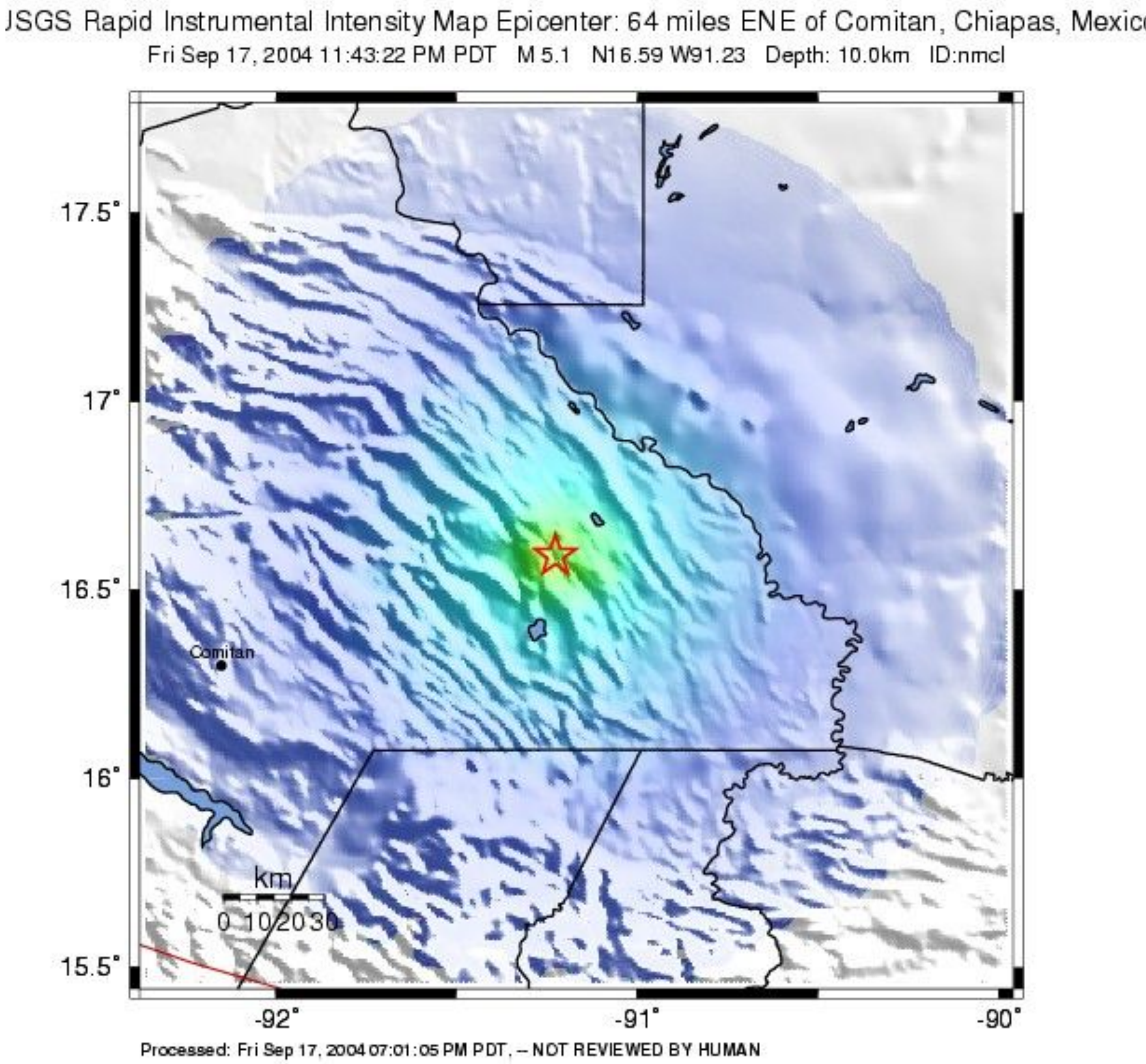

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
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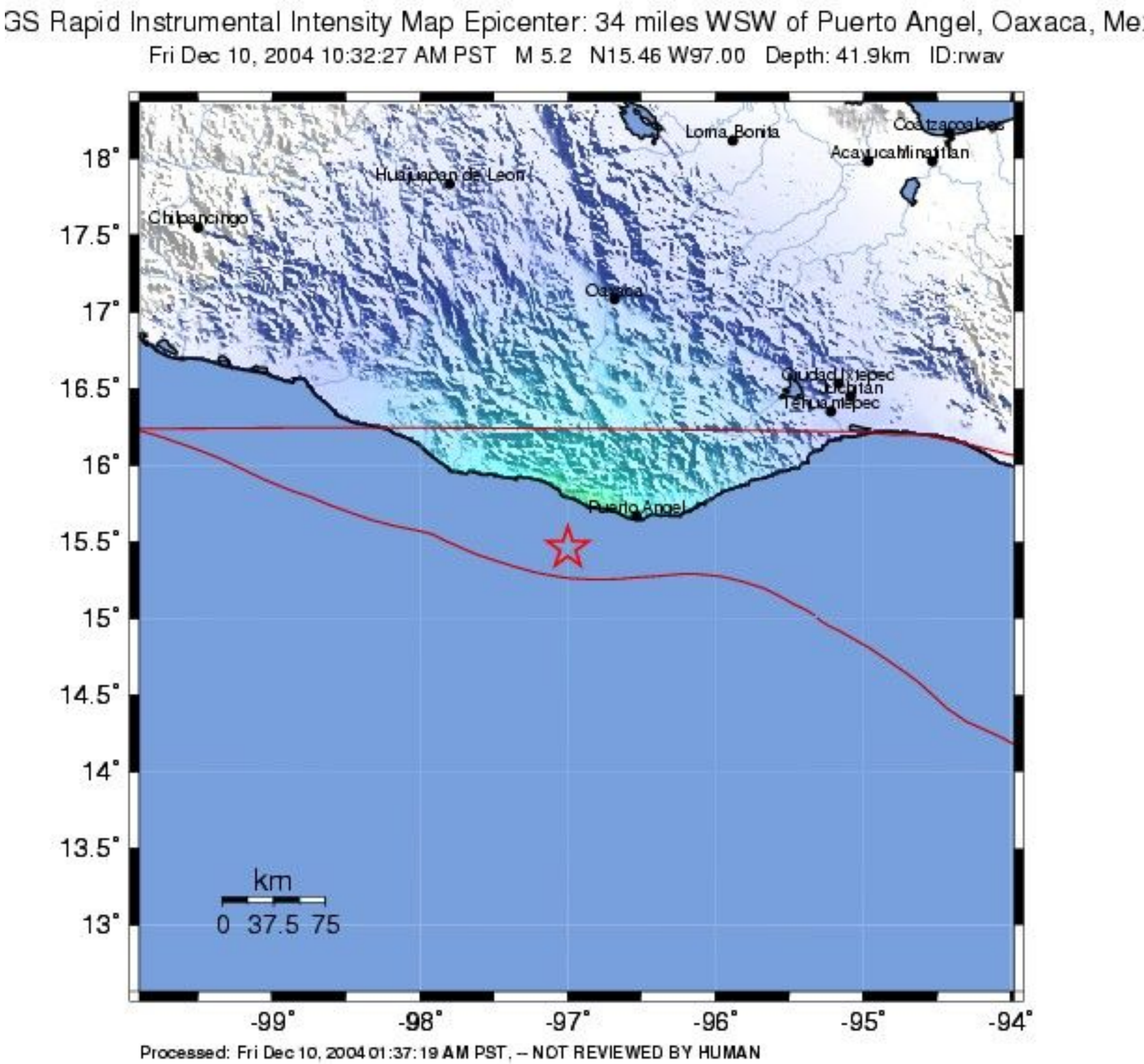

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
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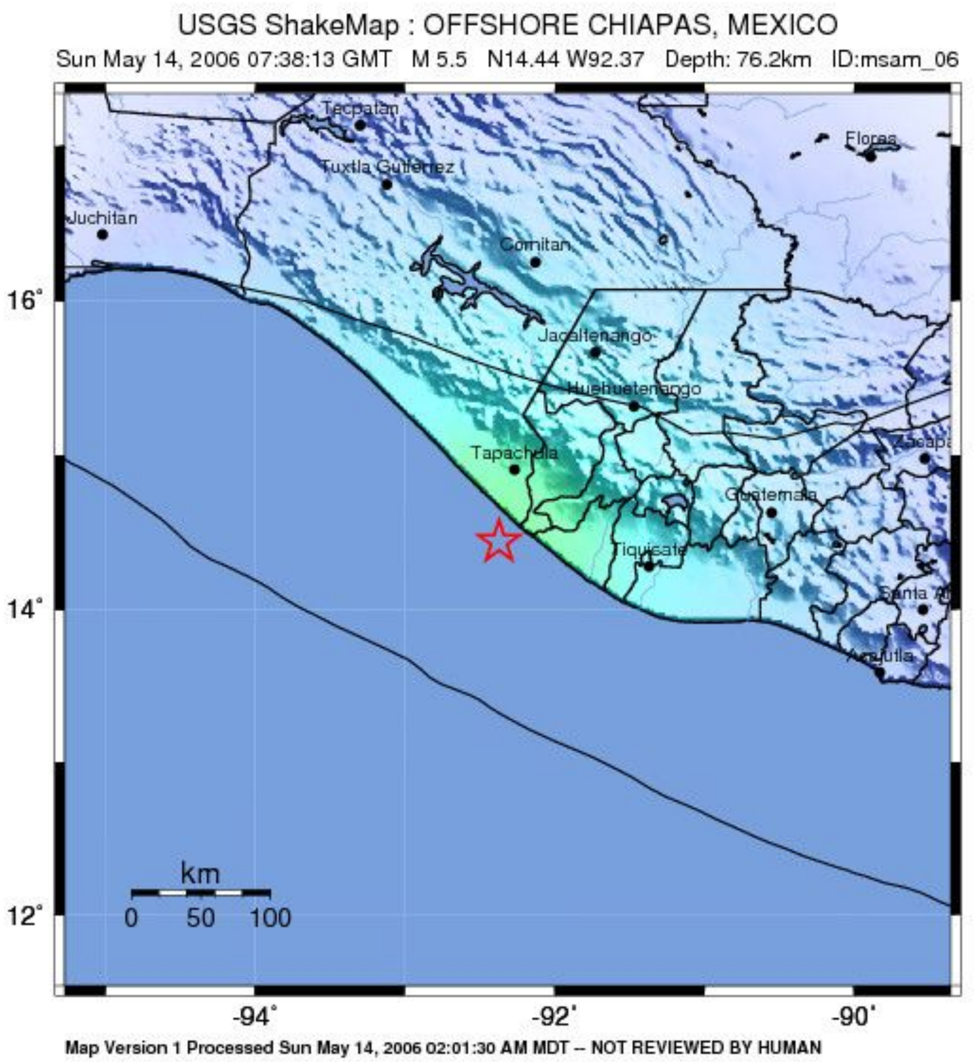
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



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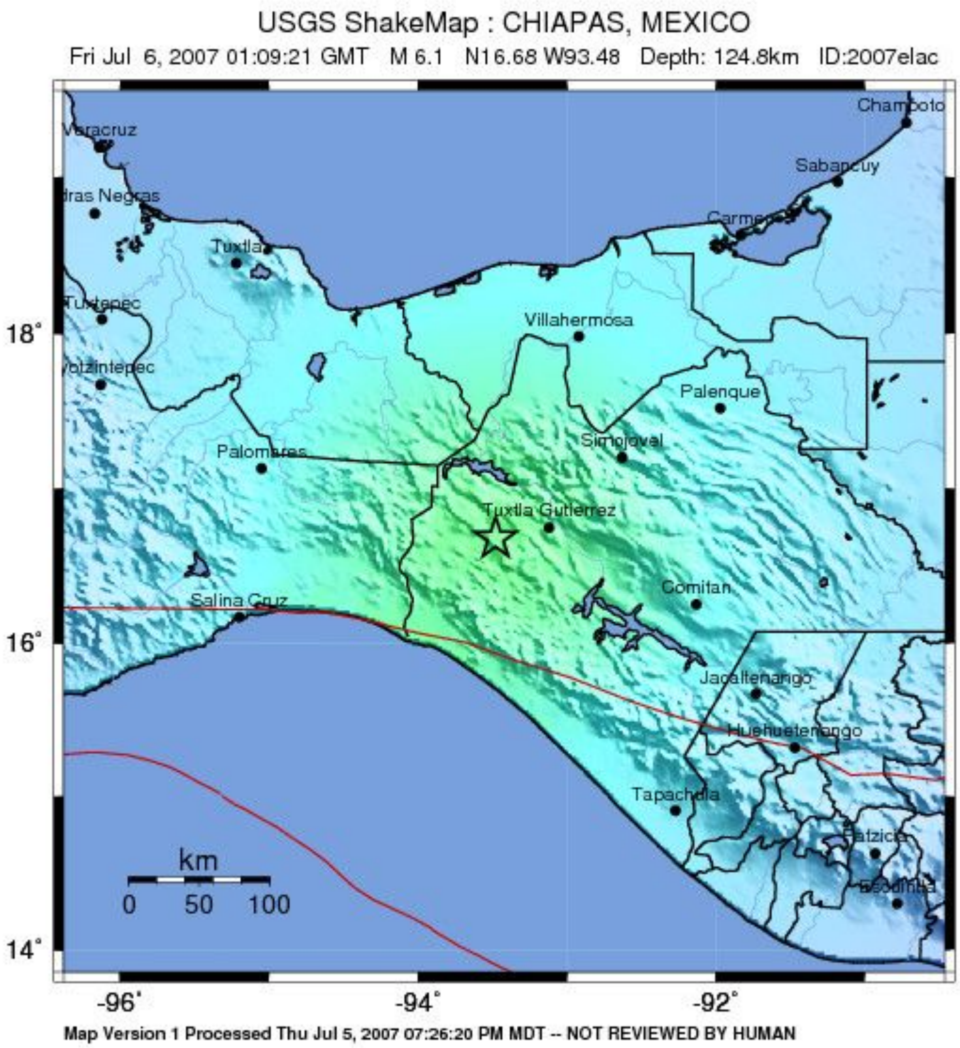
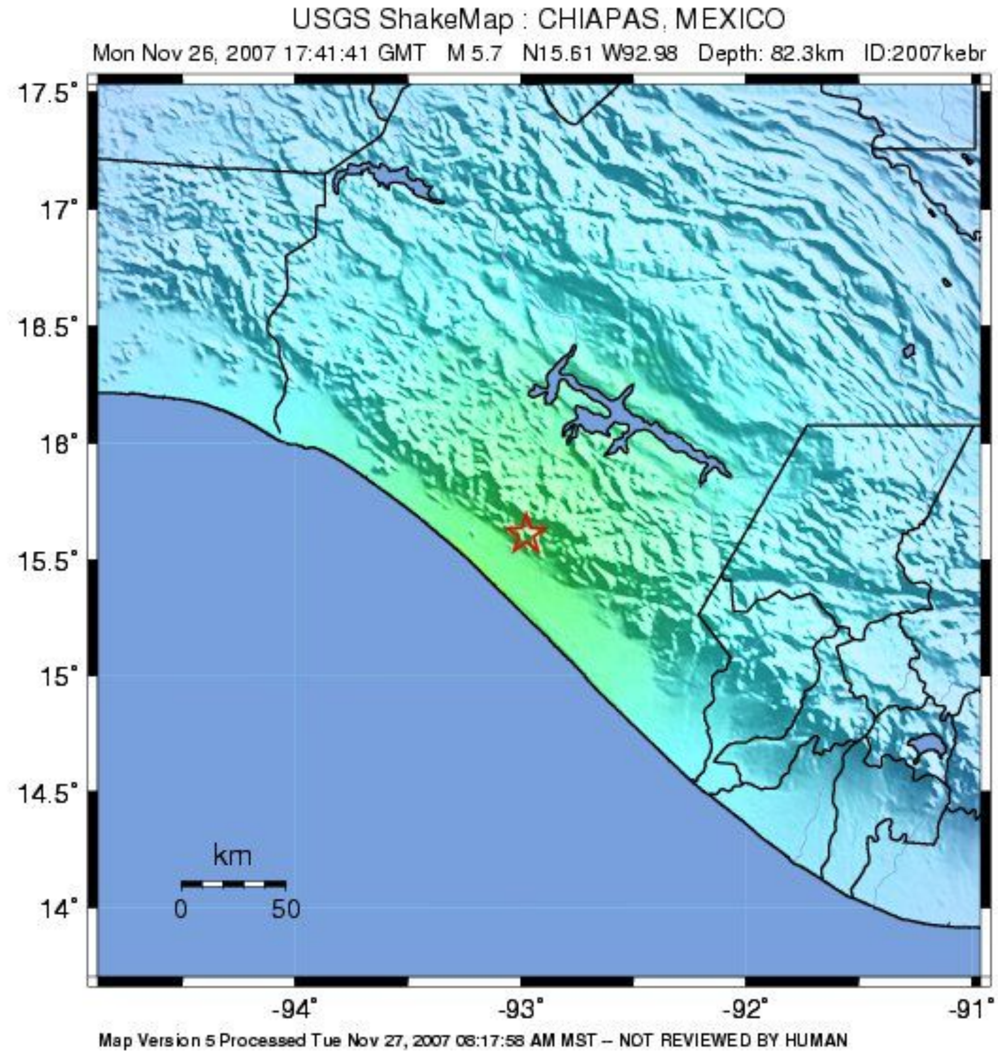
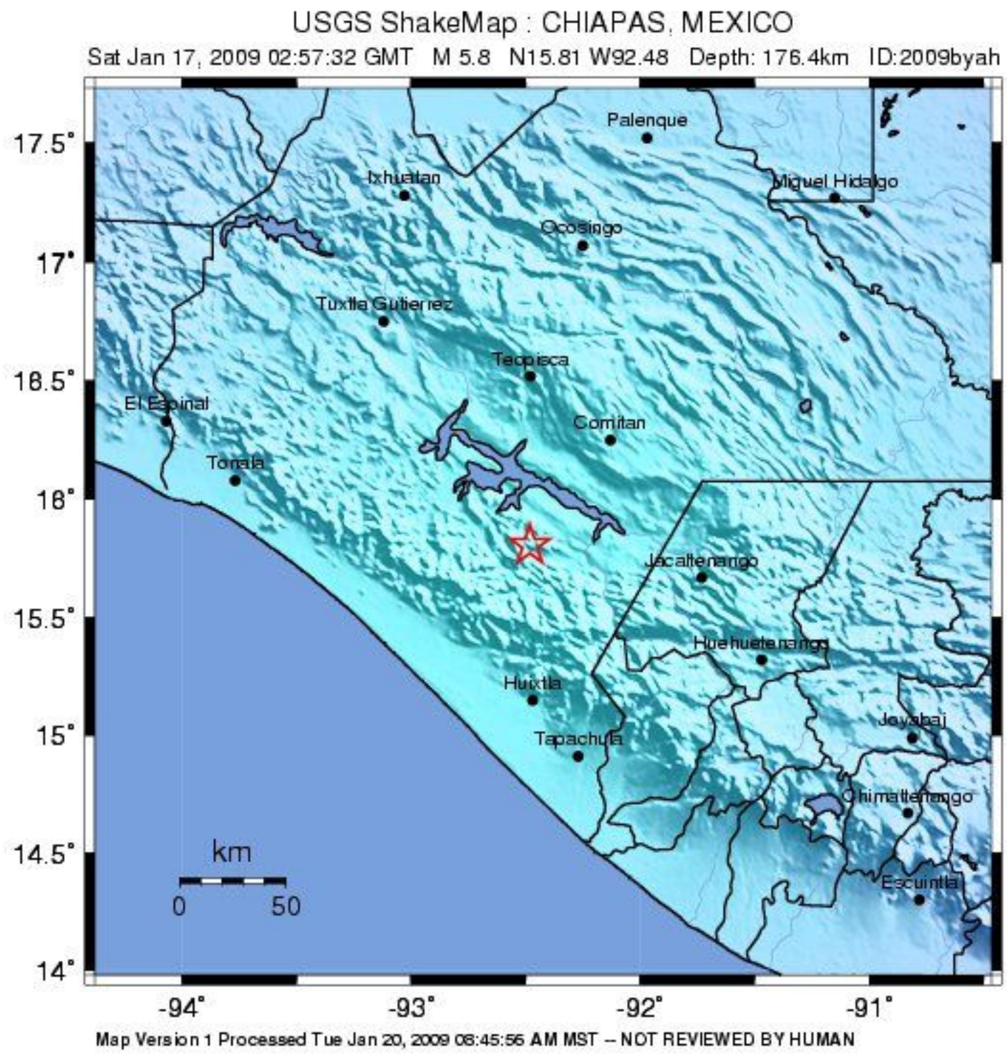
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
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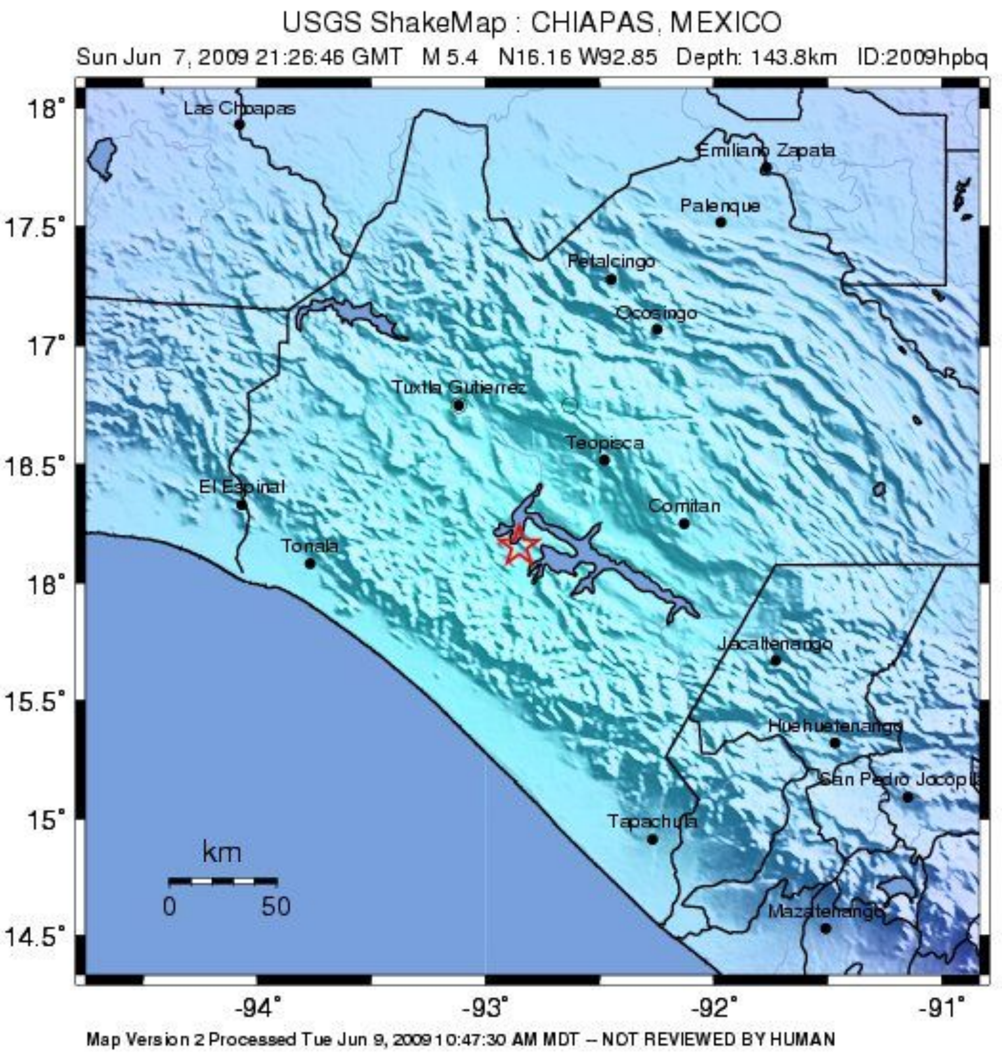

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
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PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
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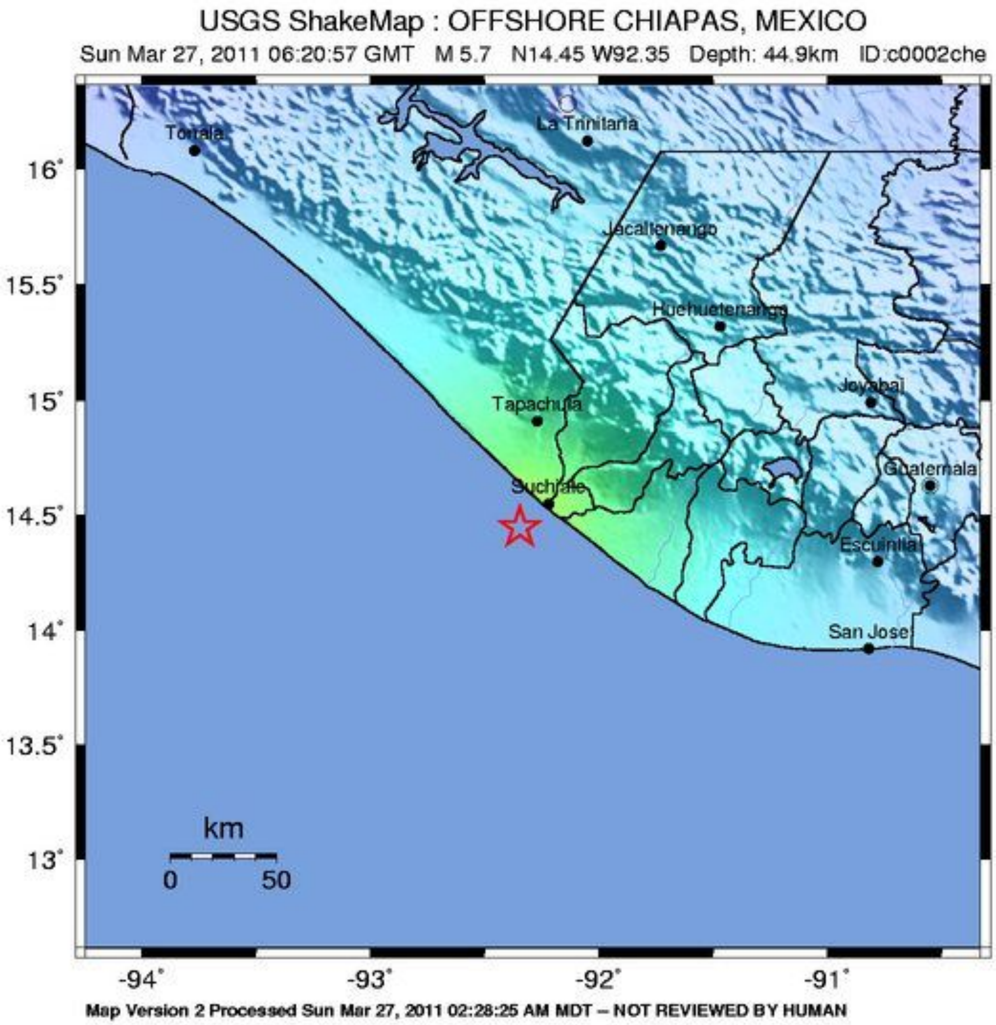
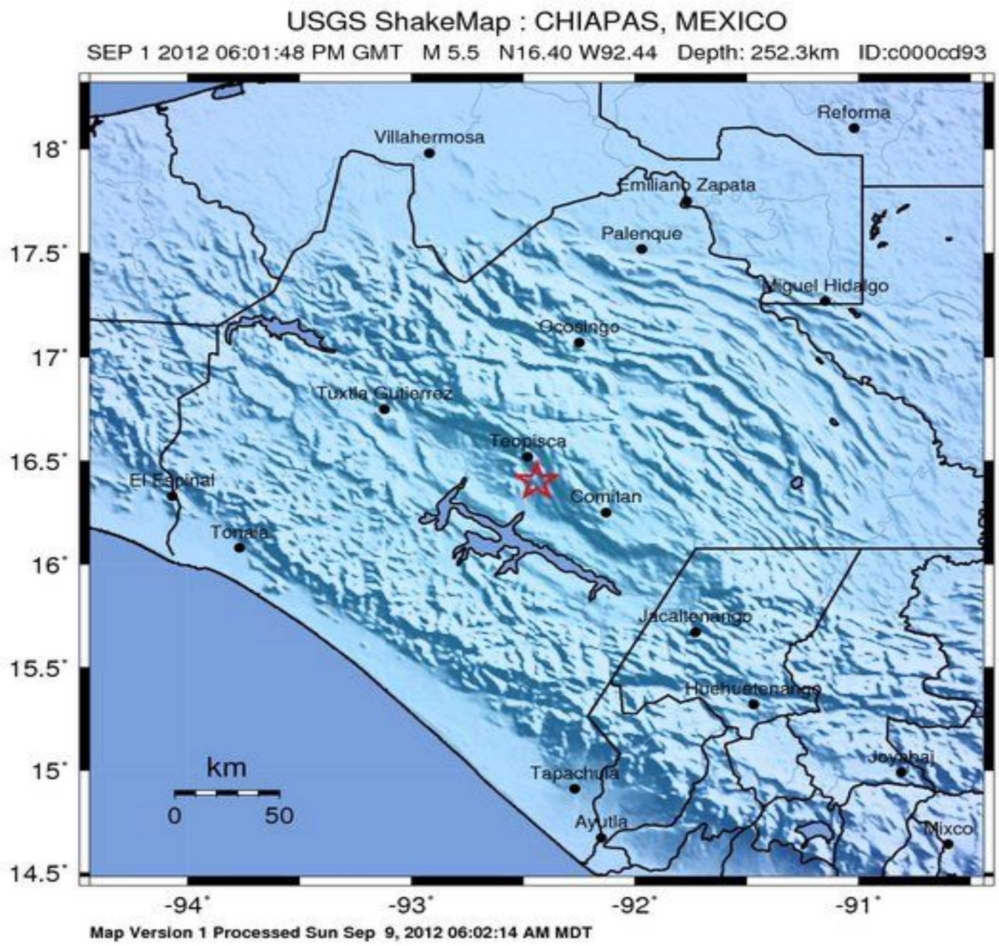
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

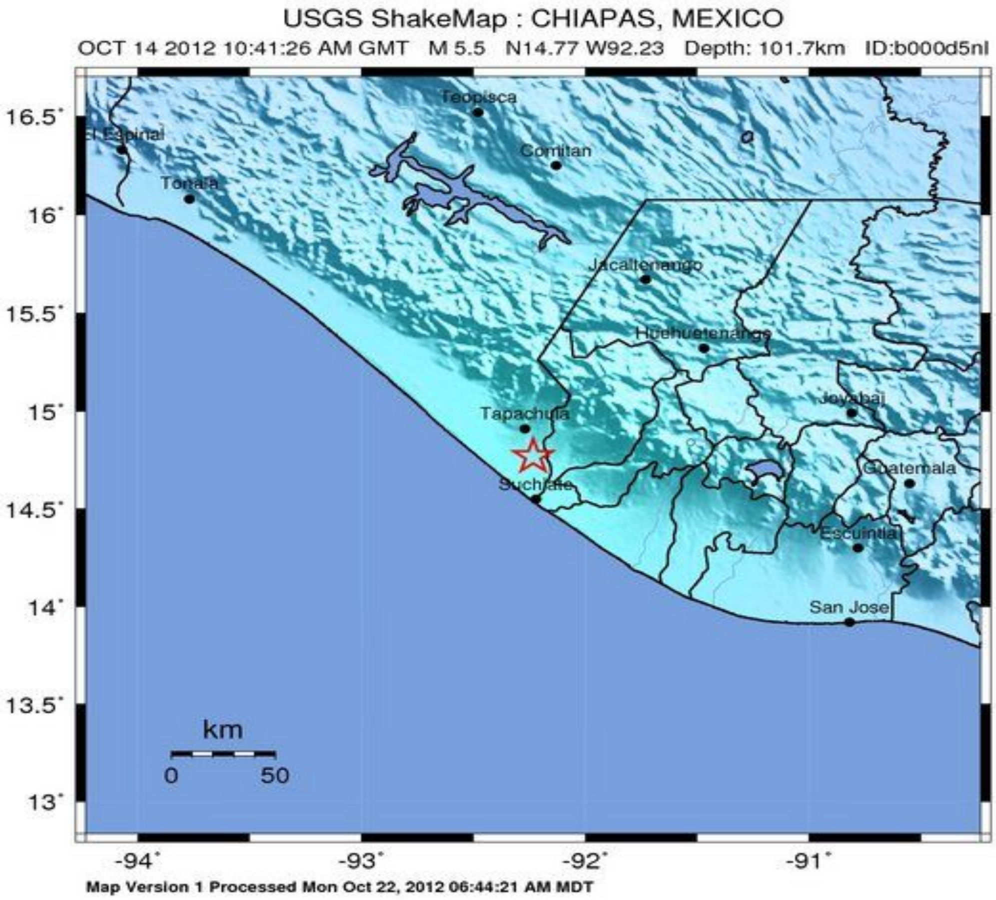


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

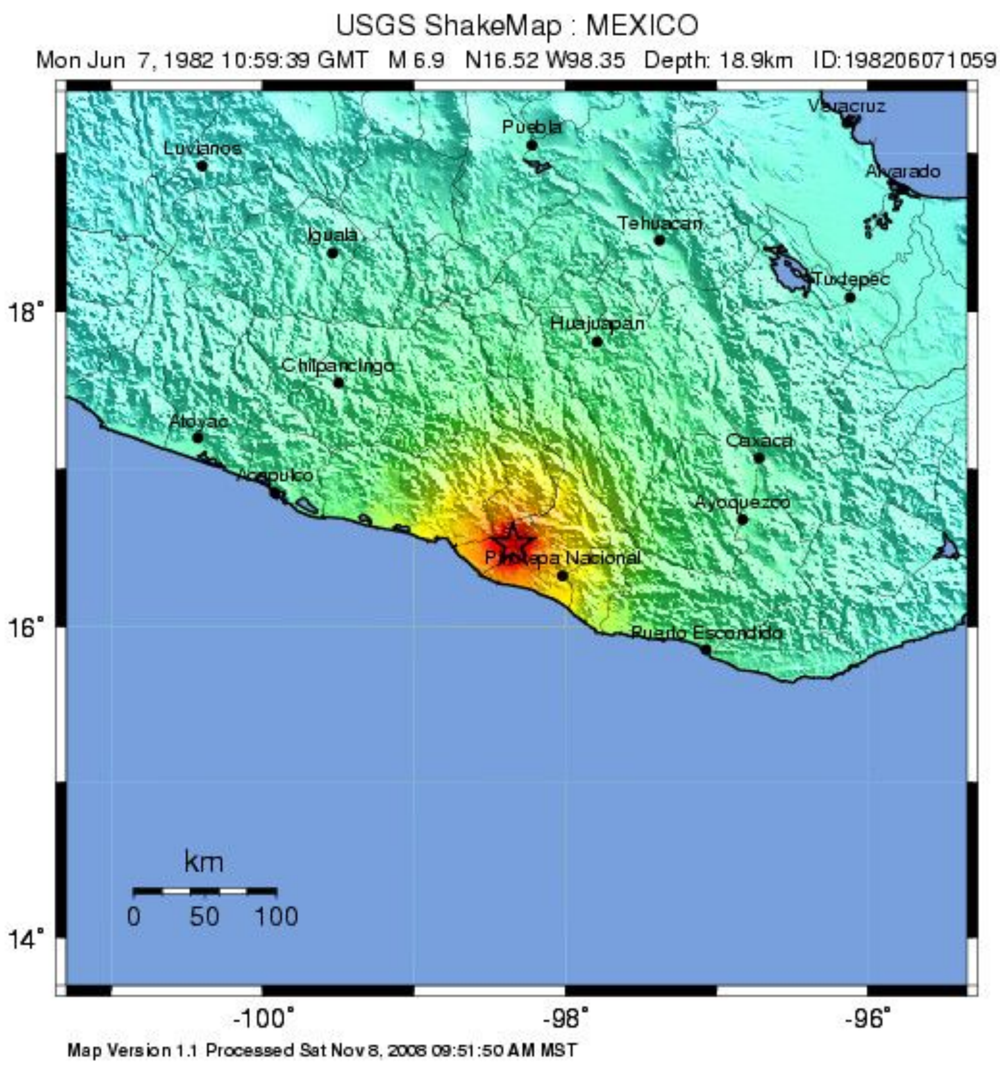
Scale based upon Worden et al. (2011)



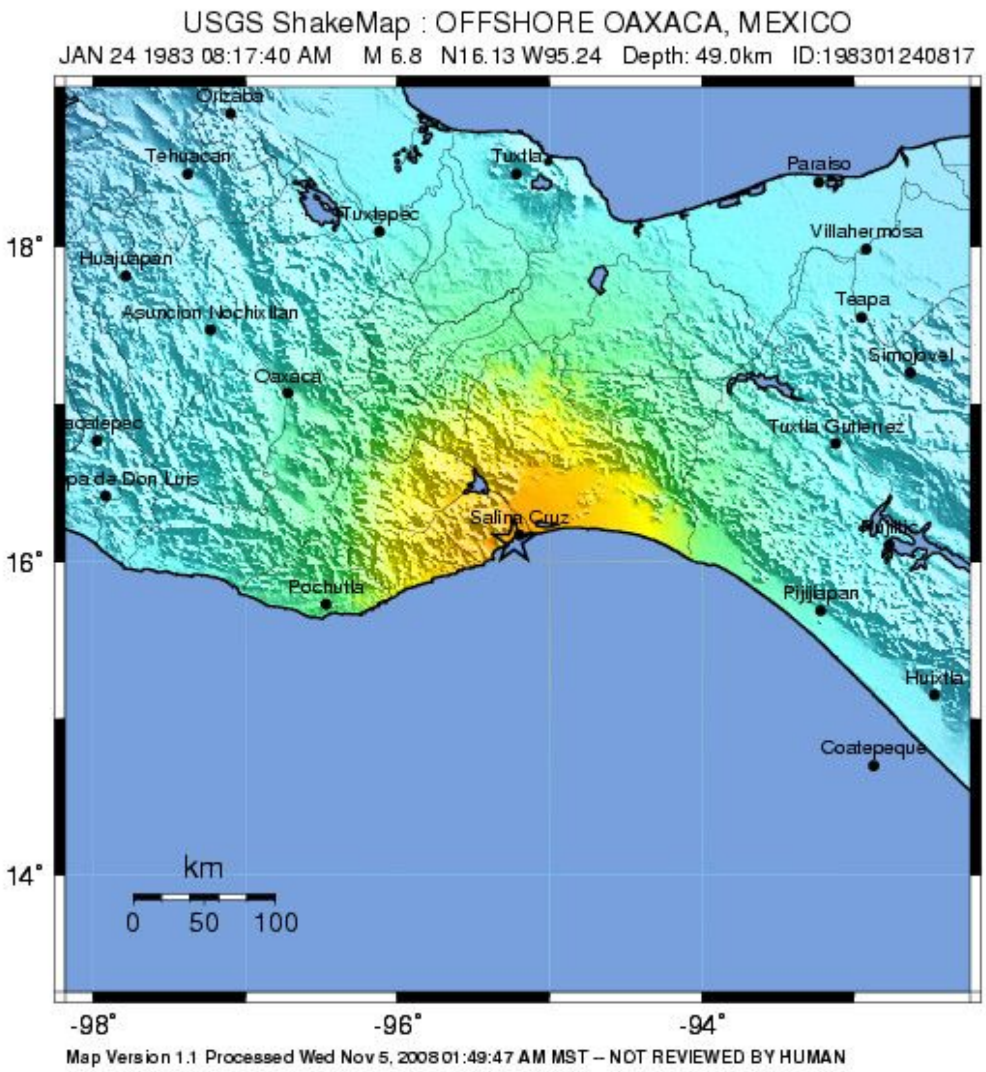
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)

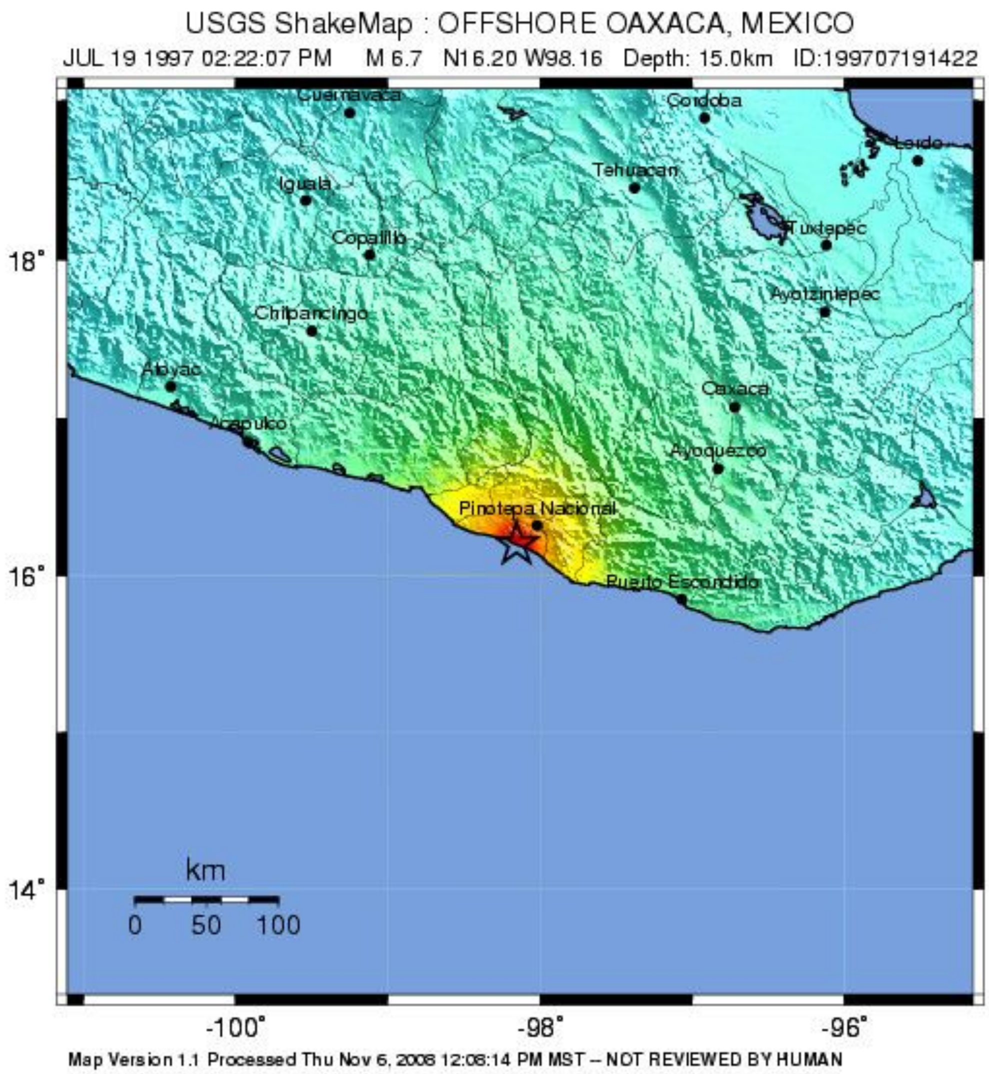
M_w 6 to 7 Earthquakes



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



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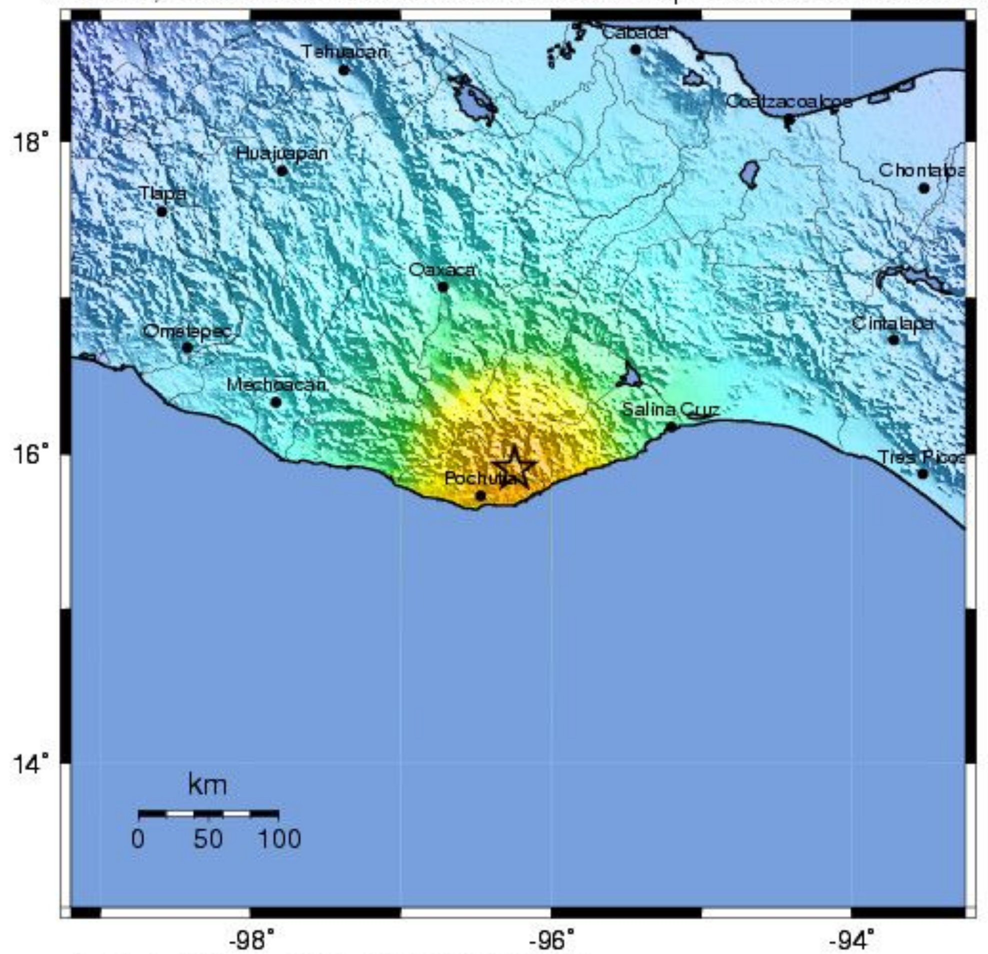
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

USGS ShakeMap : Oaxaca, Mexico

Tue Feb 3, 1998 03:02:00 GMT M 6.3 N15.90 W96.25 Depth: 24.0km ID:199802030302



Map Version 1.1 Processed Sat Nov 8, 2008 07:32:44 PM MST

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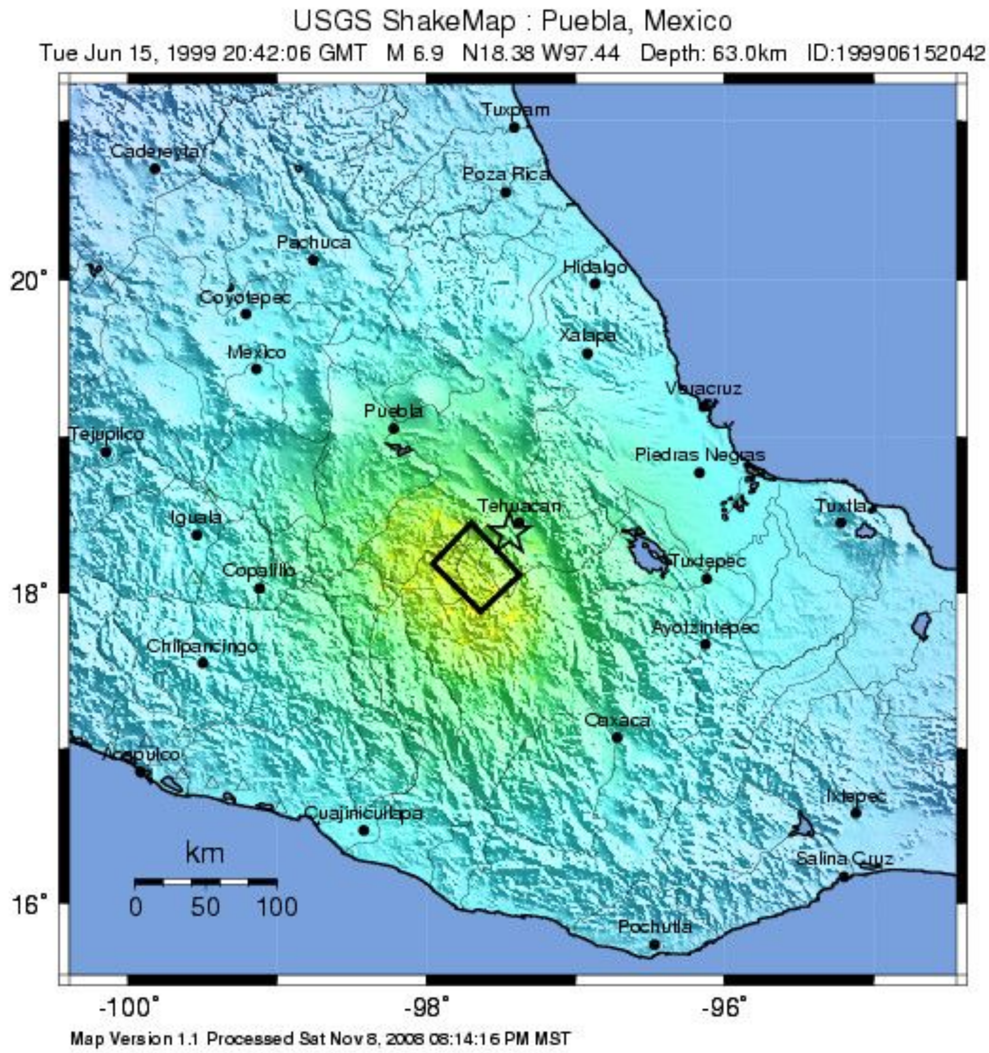

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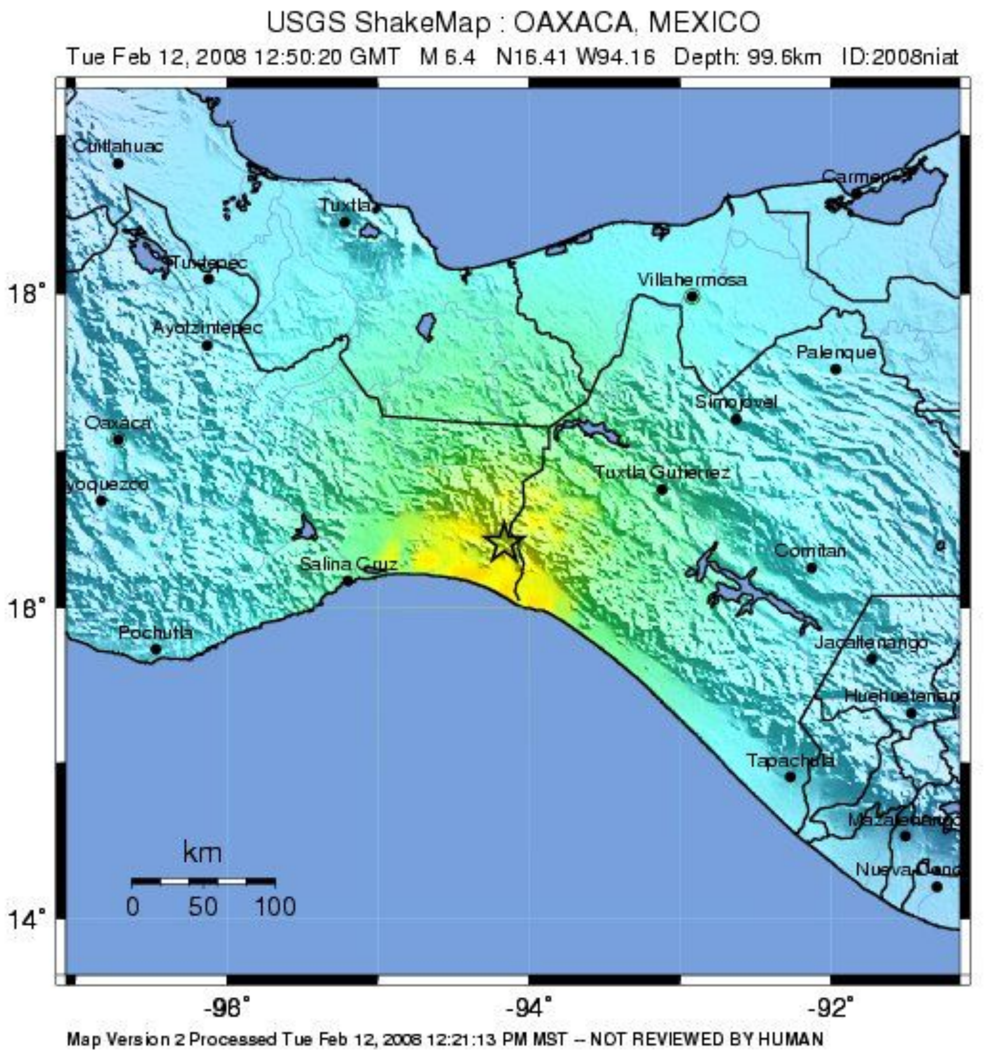

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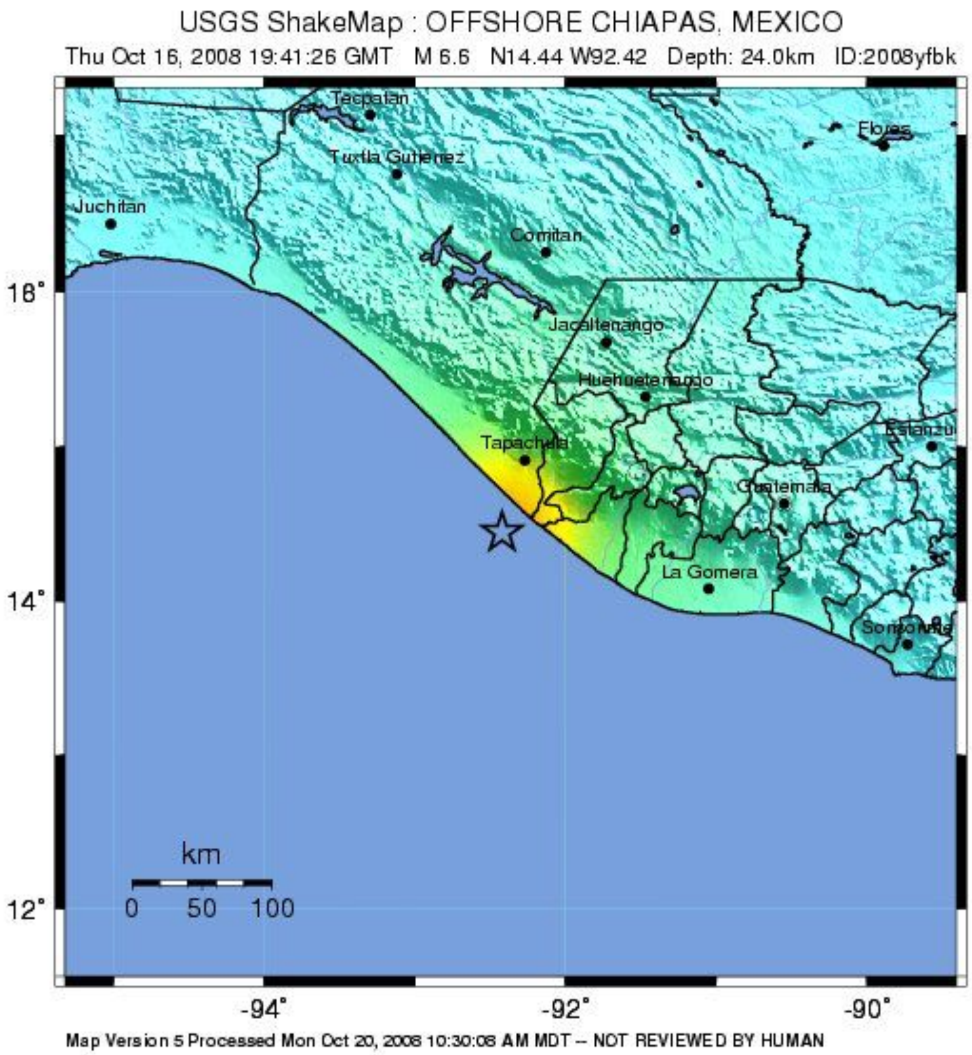

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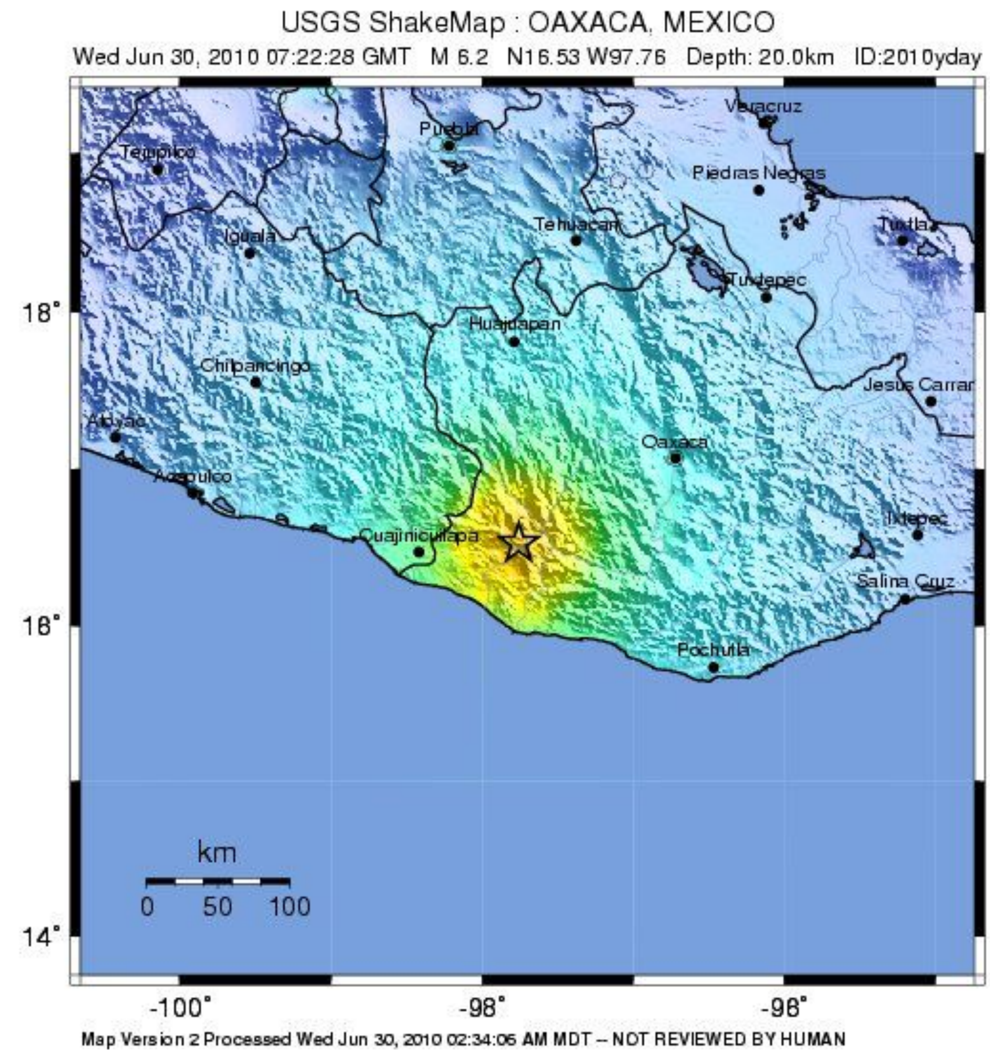

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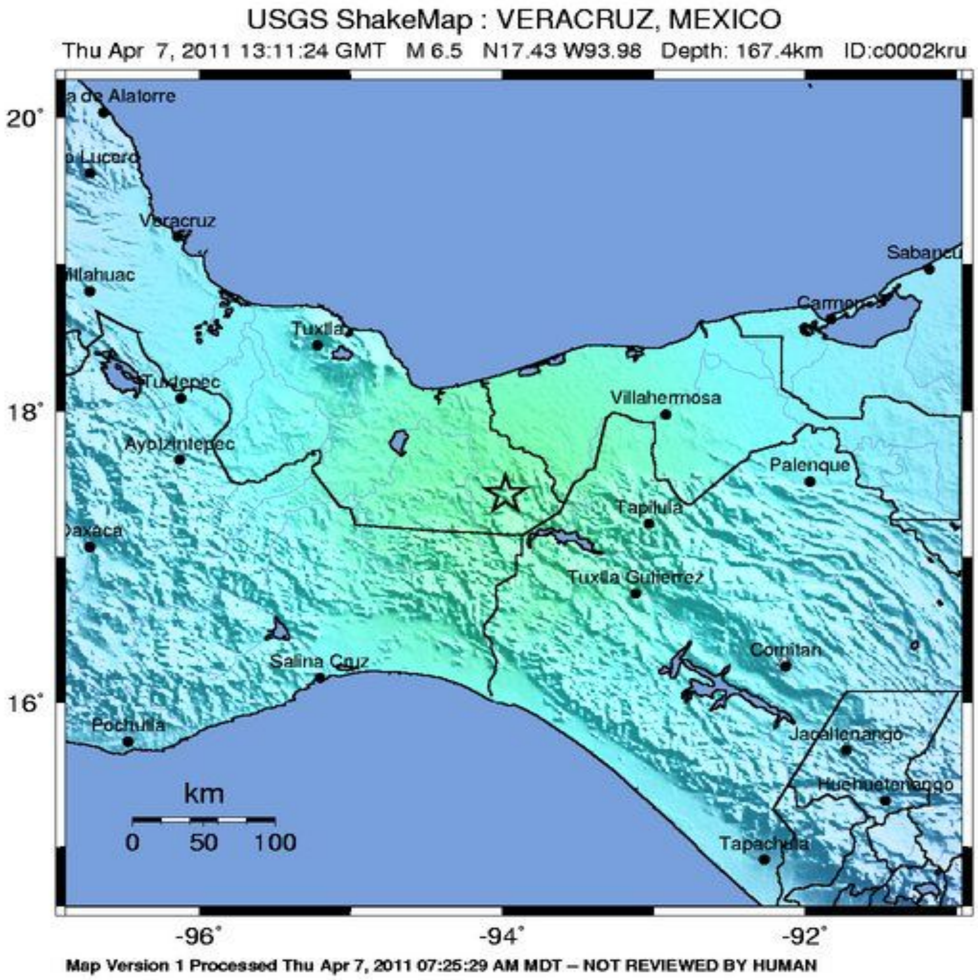

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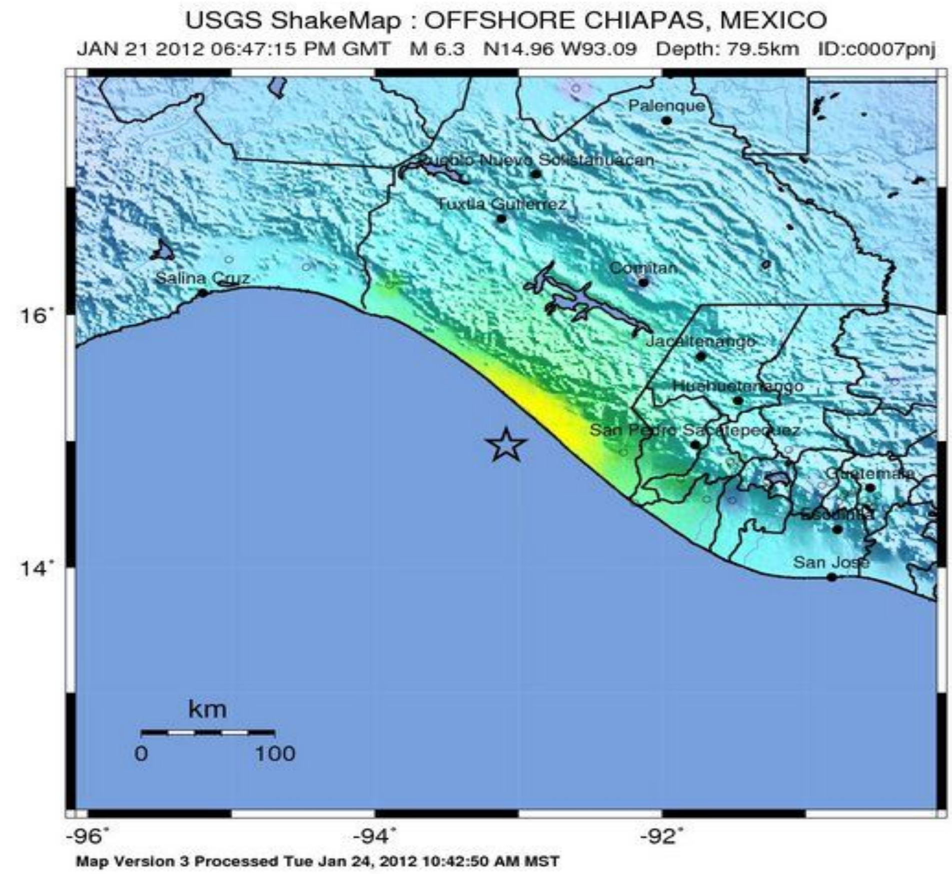

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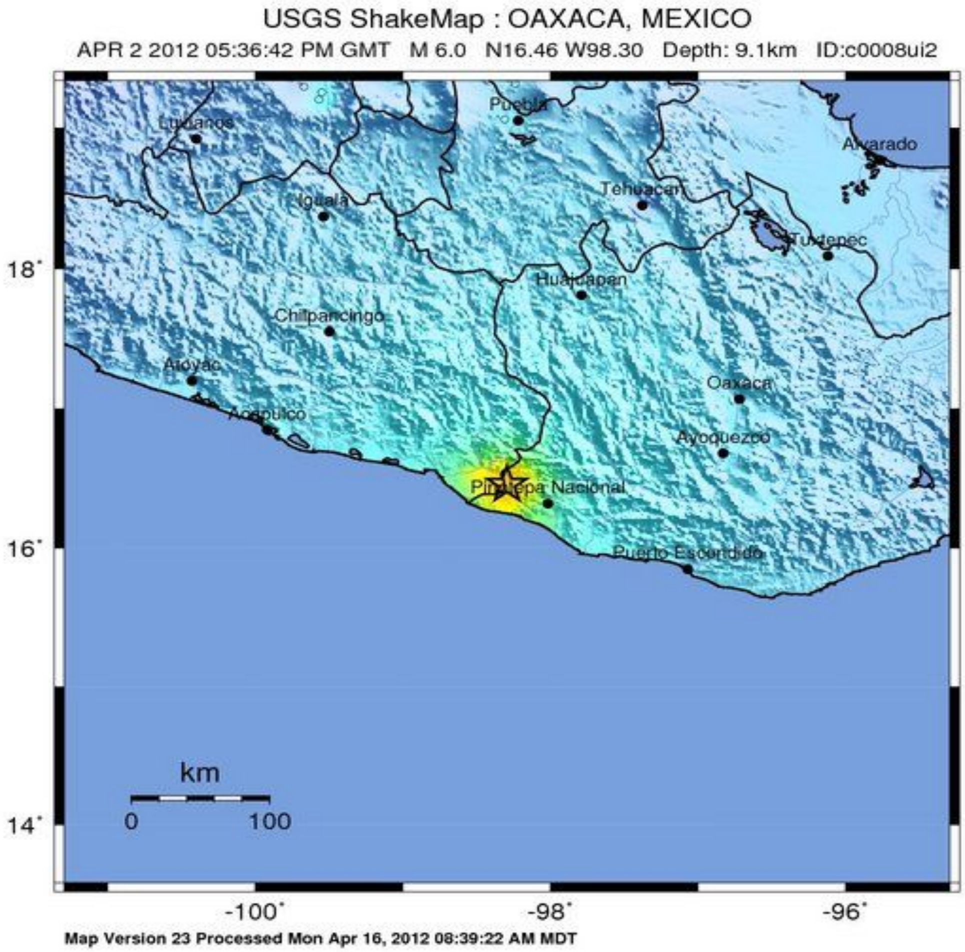
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999



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PEAK VEL.(cm/s)	*<0.01*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
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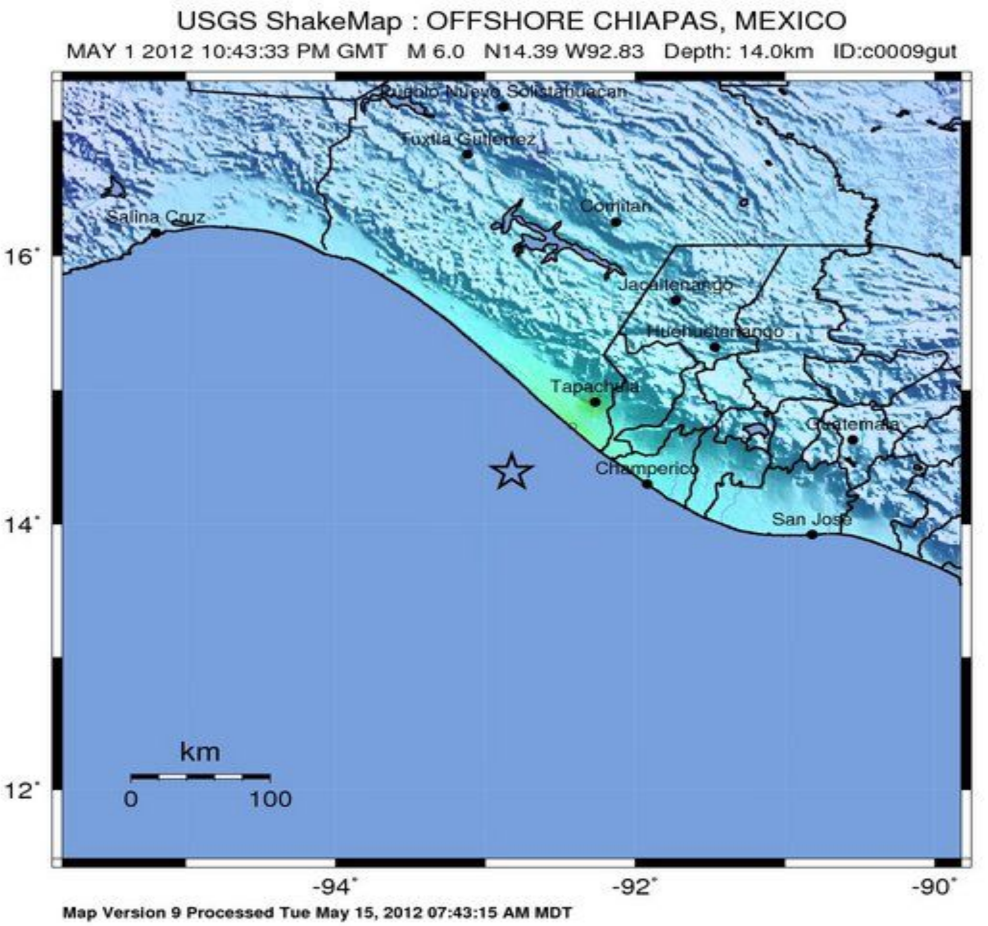

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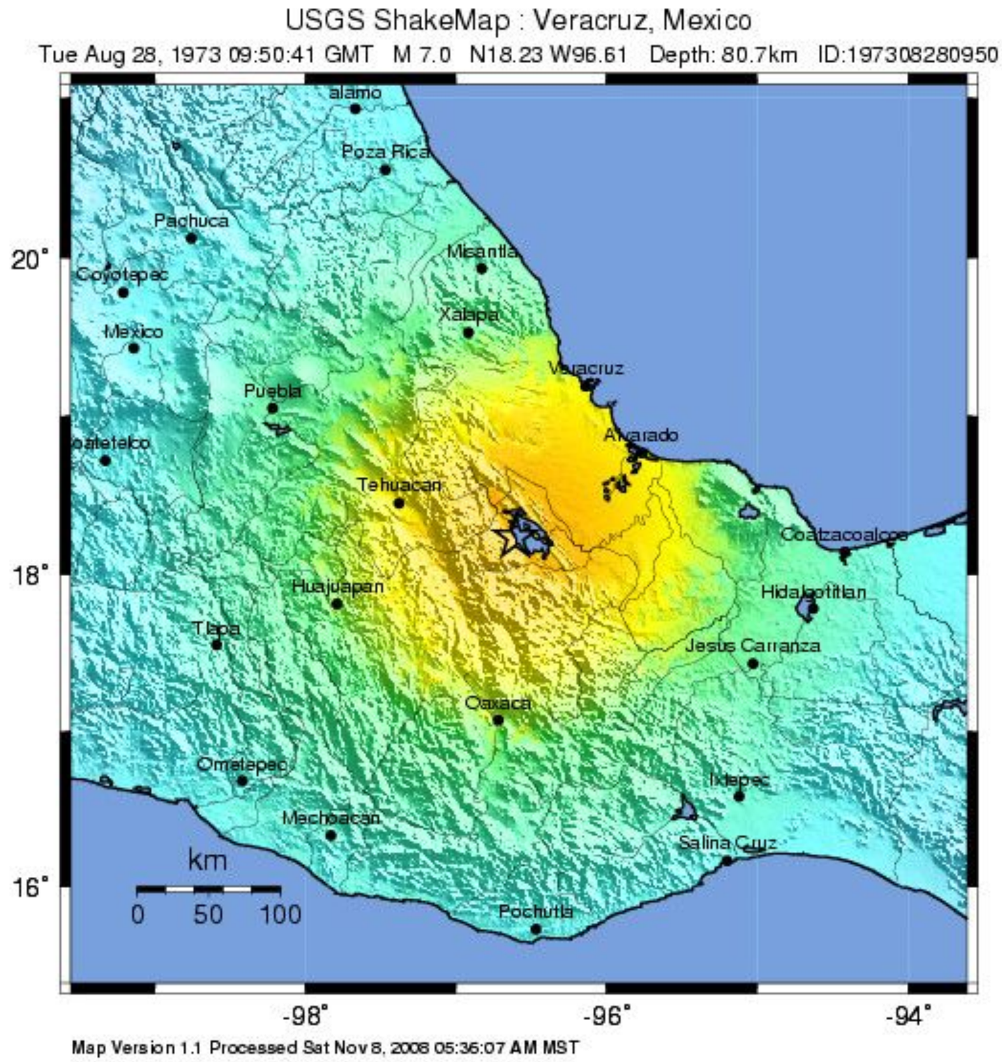
M_w7 and above Earthquakes



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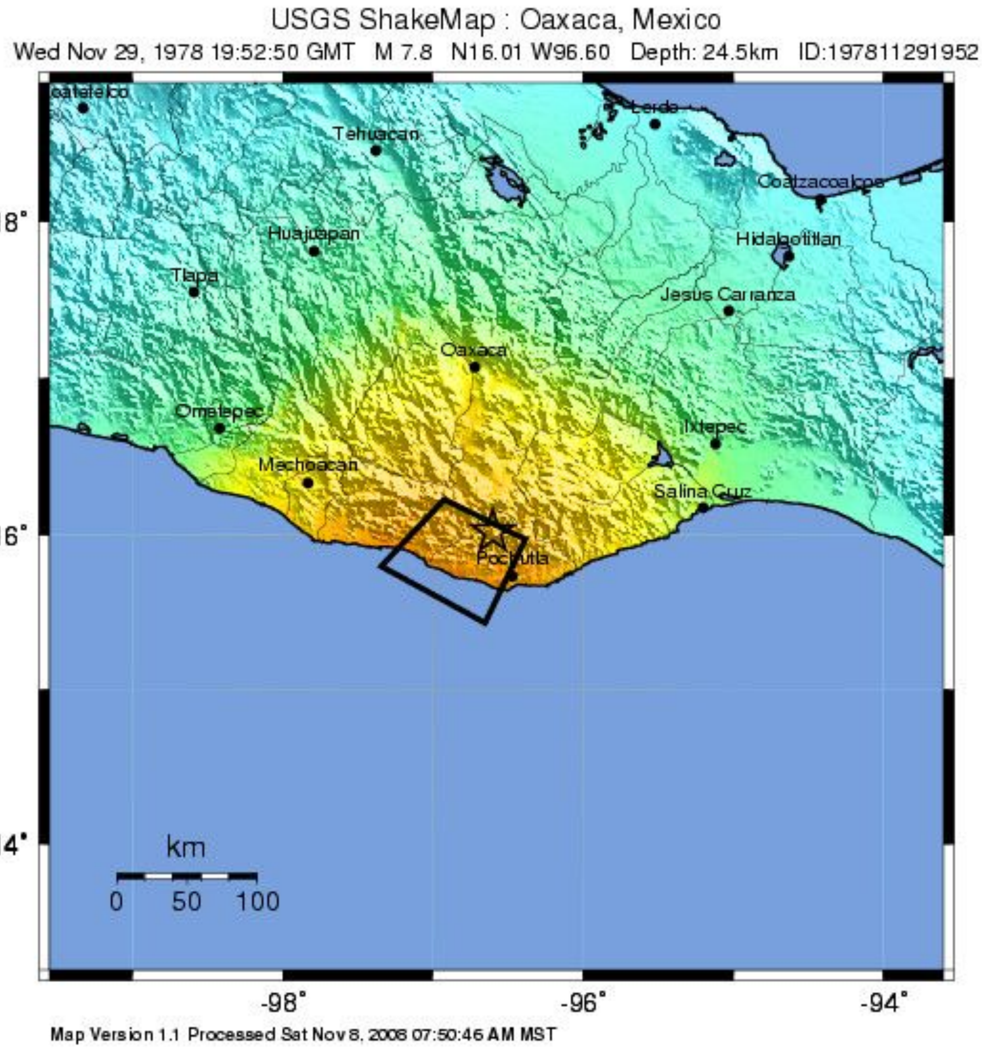

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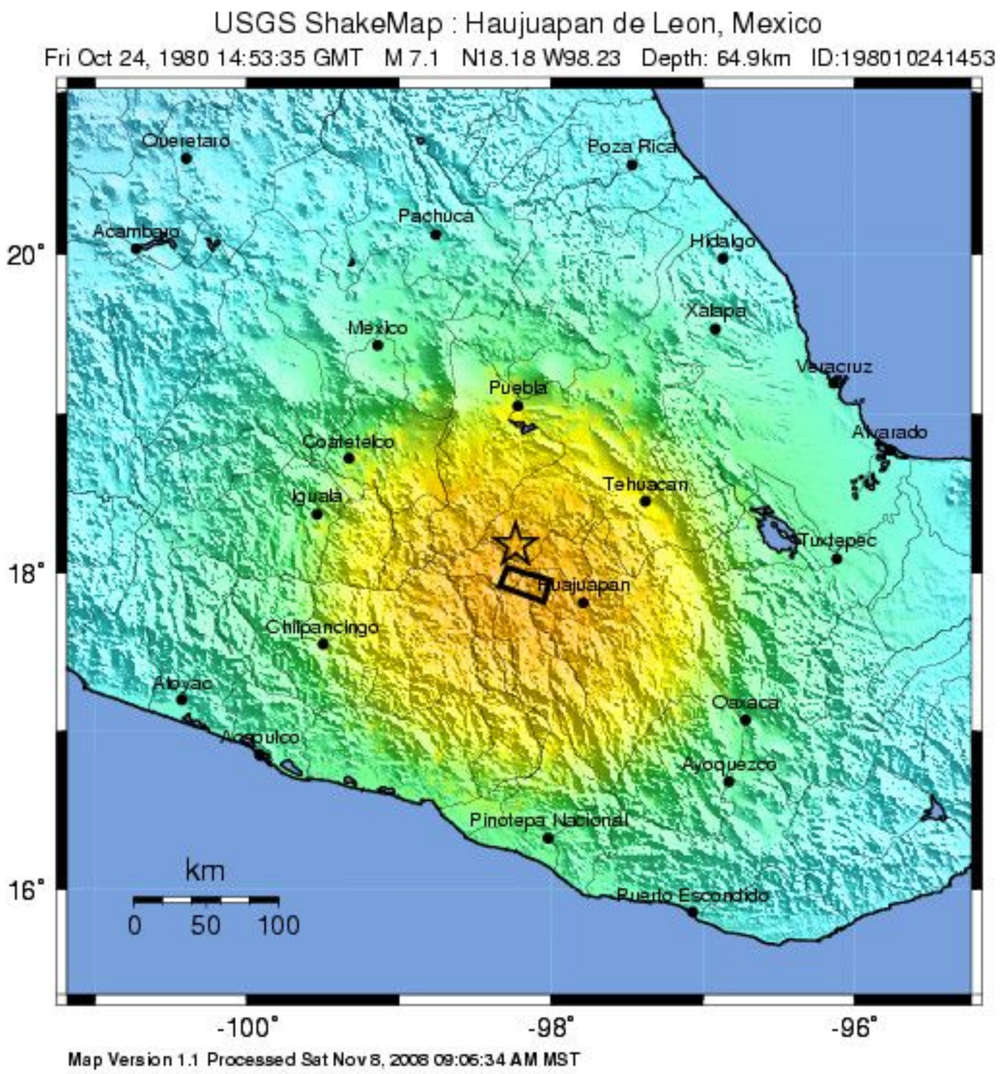

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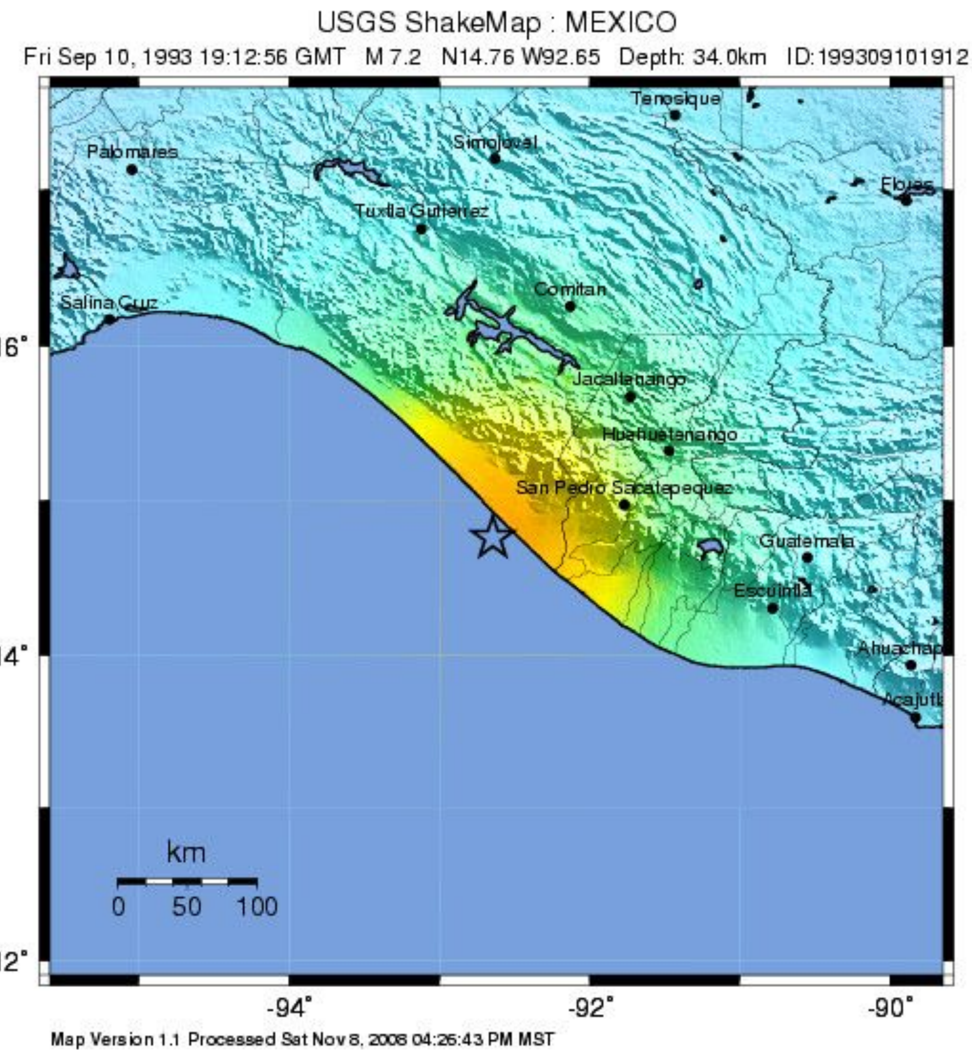

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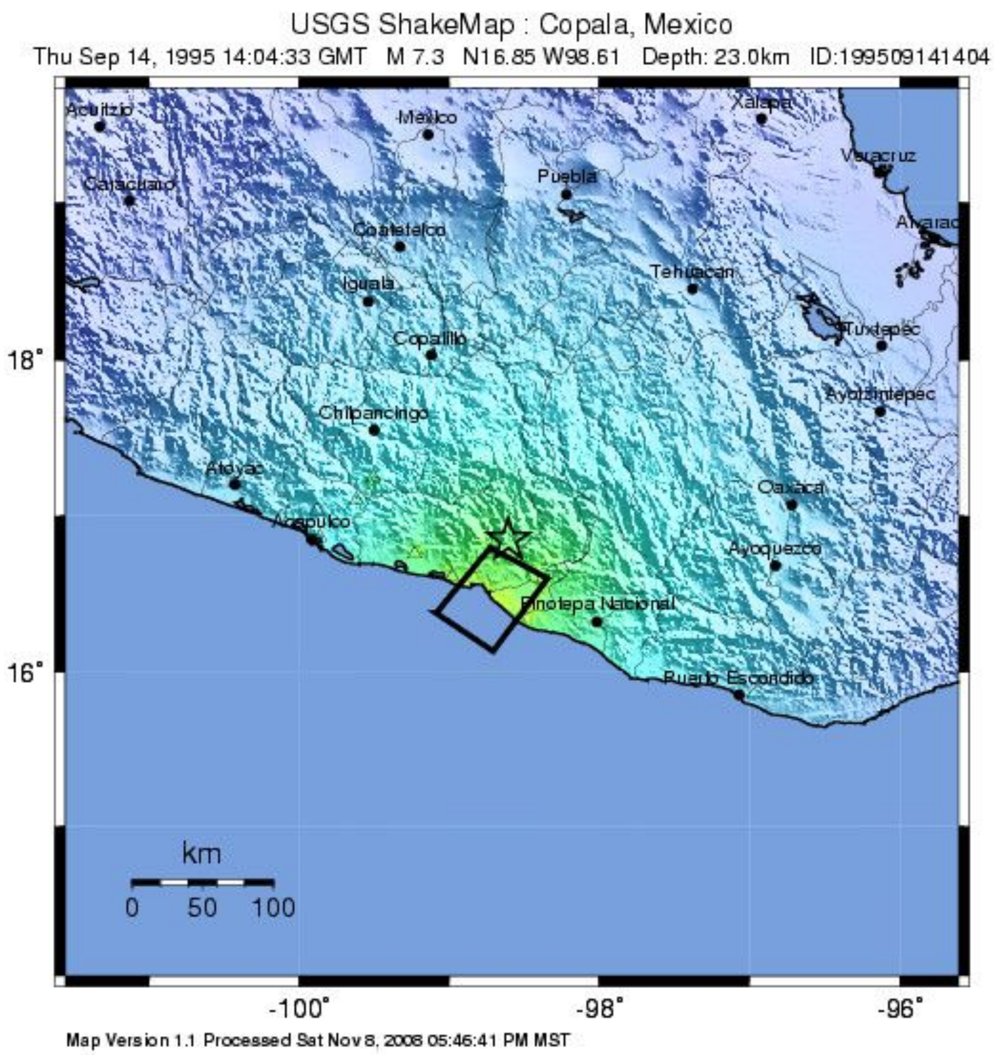

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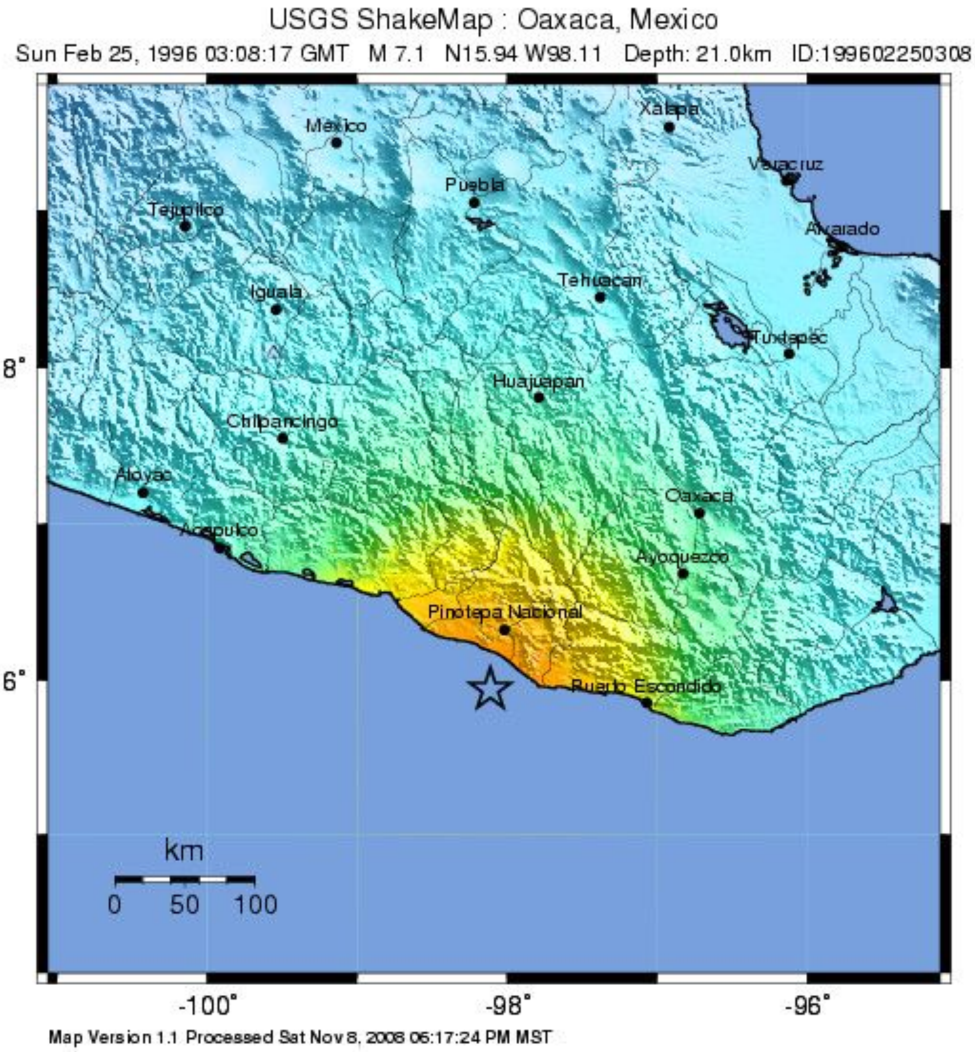

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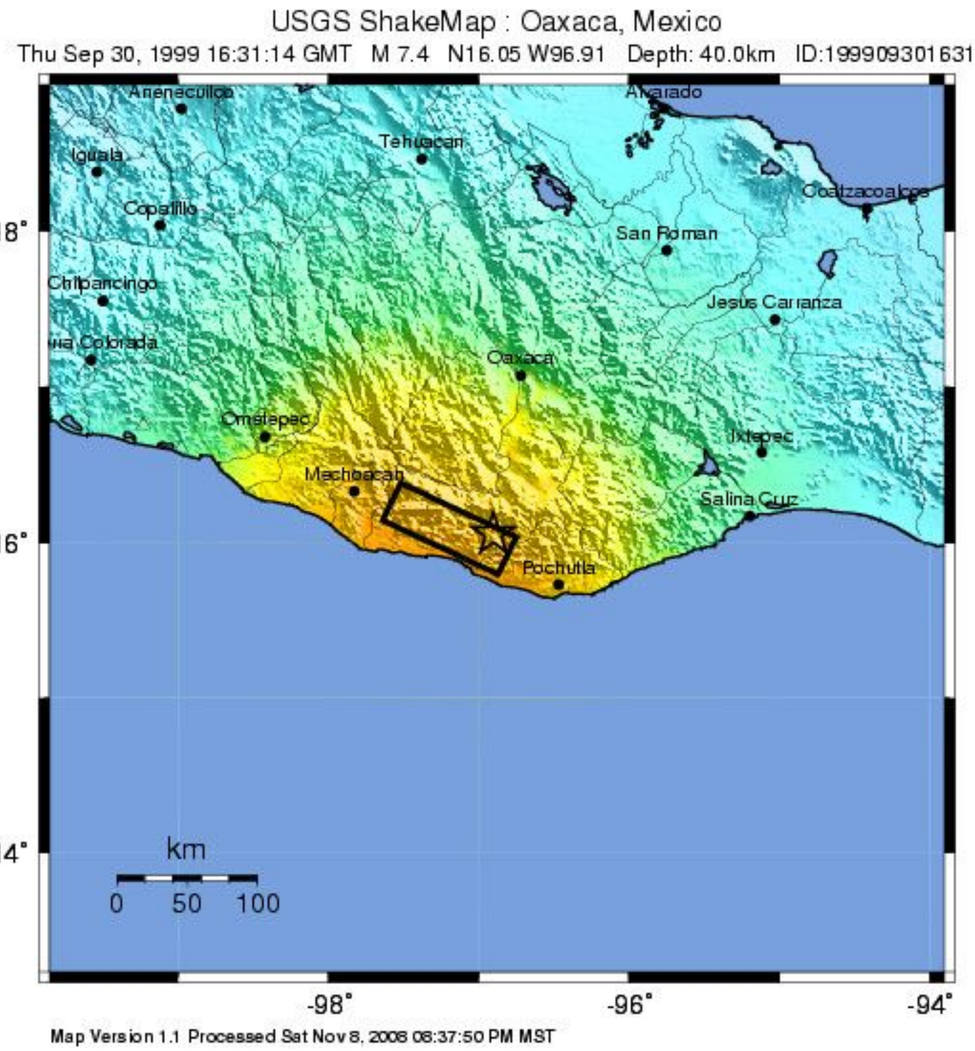

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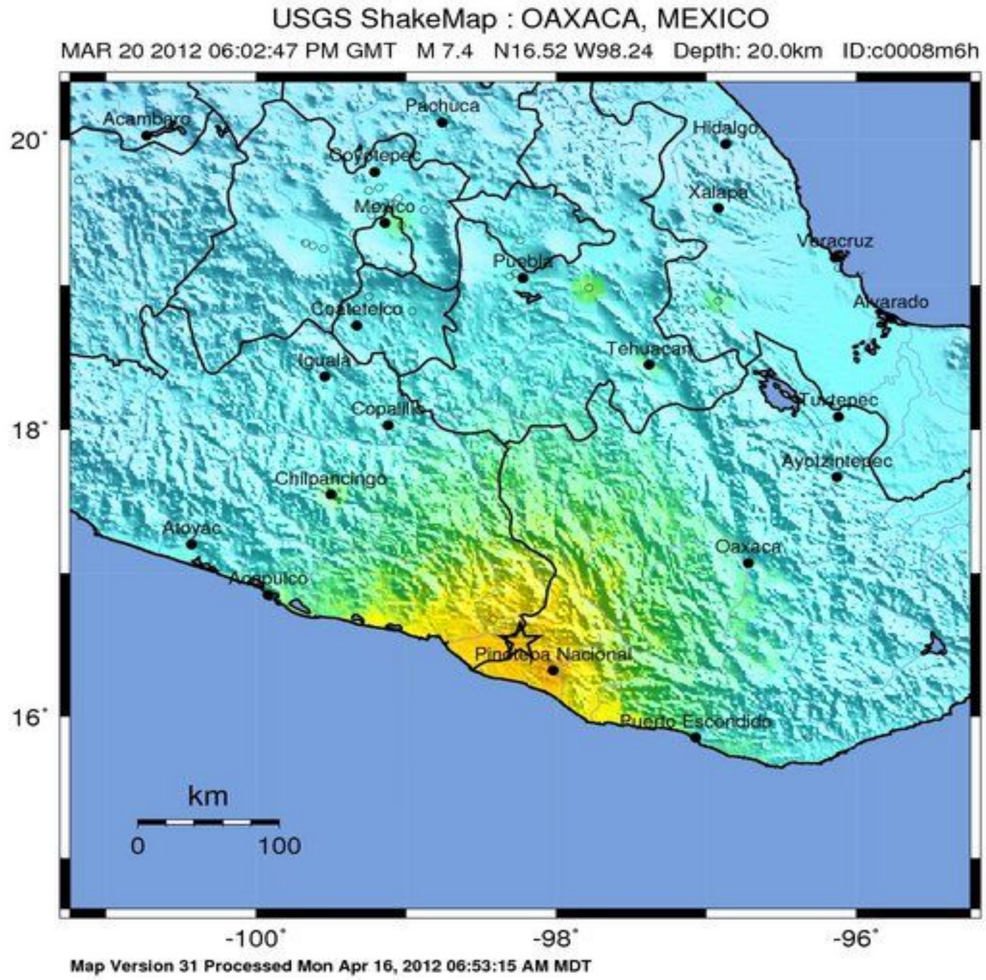

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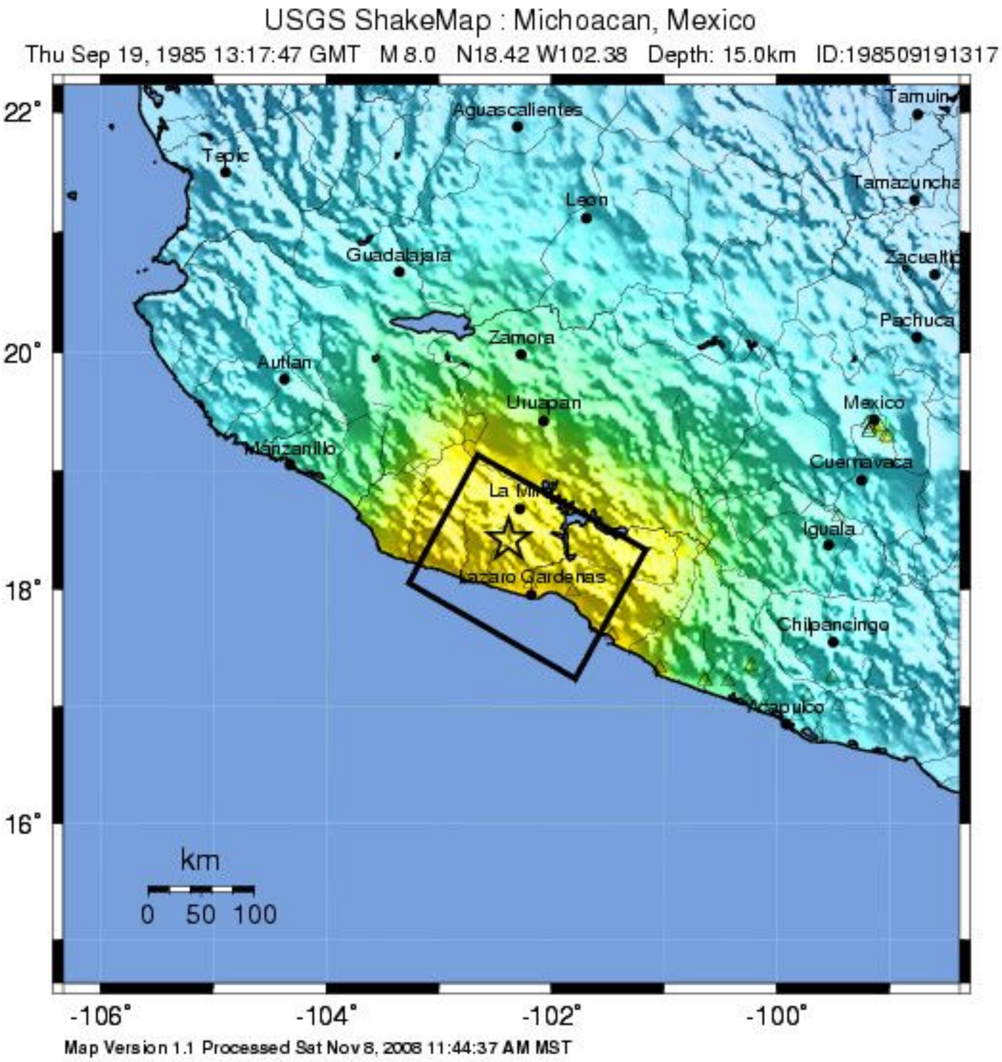
Mexico City Earthquake



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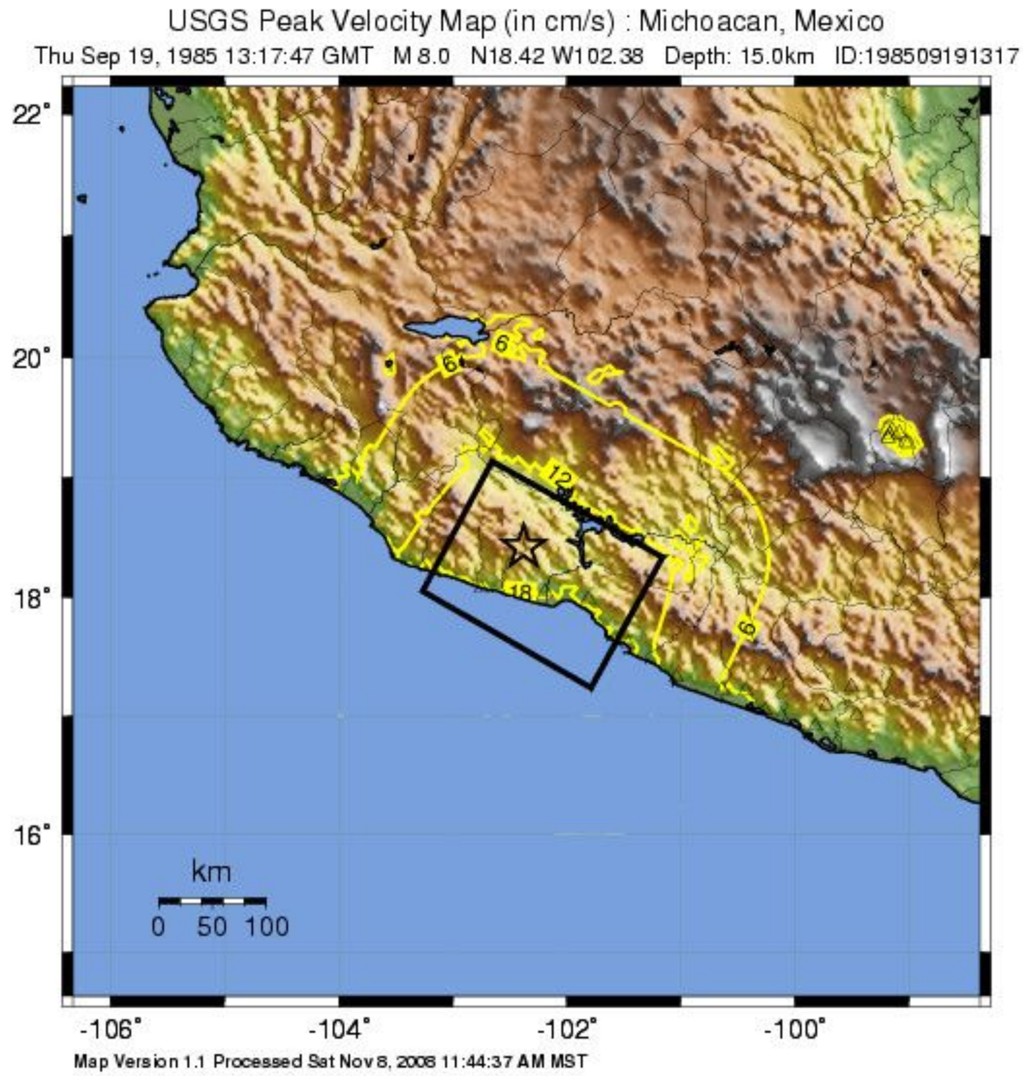


As is apparent from the Shakemaps, earthquakes of similar magnitude as the strongest volcanic earthquakes only could cause damage on a very limited local scale. In order to account for the destruction described in 3rd Nephi, it is clear that a volcano *and* a regional earthquake are indicated.

Non-Volcanic Storm Events

Relying on two premises, Kowallis (1997) and Ball (1993) both assert that nothing beyond a volcanic event is necessary to explain the disaster described in 3rd Nephi, excluding a storm. The first premise is the reference to "exceedingly dry wood" in 3rd Nephi 8: 21 which states:

> And there could be no light, because of the darkness, neither candles, neither torches; neither could there be fire kindled with their fine and ~~exceedingly~~ [exceeding] dry wood, so that there could not be any light at all;

The argument was that it would not be likely that wood would have been exceedingly dry if the wood had just been exposed to a hurricane or a large tropical storm. This argument does not seem at all consistent with the language in the verse itself, as the Book of Mormon author appears to be simply listing all the types of artificial light that inhabitants were capable of igniting, and pointing out that they could not ignite any of them. If anything, it would seem to indicate that the author is trying to emphasize that the wood they were trying to ignite was indeed dry, not the wet wood that would be ubiquitous in light of a large storm.

The Book of Mormon peoples were no doubt aware of local precipitation cycles, namely that there is an annual rainy season that typically lasts from May to November that includes heavy tropical rains. It would be unreasonable to assume that they did not have methods and locations to protect their firewood from tropical precipitation.

The second premise presented by Kowallis and Ball is that the word "rain" is never specifically mentioned as part of the "great storm." This argument seems to assert that the definition of the word "storm" would not normally include precipitation unless the word rain was somehow used as a descriptor.

At this point, while meteorological analysis is not the primary purpose of this book, it will be useful to evaluate some of the meteorological terminology found in the Book of Mormon.

All of the verses in the Book of Mormon that contain the word (or a derivate of the word) "storm," "tempest," "rain," "flood," "wind," "whirlwind," "thunder," "lightning," and "tumultuous noise" were examined. In examining the verses related to these terms, the primary purpose is to determine if a phrase, verse, or series of verses is so structured that it identifies individual terms as being more or less mutually exclusive, meaning that they are different and distinct events or items. Additionally, the verses can also determine if these terms are related or otherwise described sufficient to further differentiate between their meanings.

The following verses, although containing one or more of these terms, were not considered in the analysis because they were not relating to weather or natural hazard terminology, or were derived from external records or implied other non-Mesoamerican sources (i.e., Old Testament scriptural references, teachings of Jesus, etc.): 1 Nephi 17:45, 2 Nephi 14:6, 2 Nephi 15:6, 2 Nephi 15:28, 2 Nephi 17:2, 2 Nephi 21:15, 2 Nephi 23:4, Mosiah 27:11, Mosiah 27:18, Alma 10:22, Alma 29:2, Alma 36:7, Alma 38:7, 3 Nephi 11:40, 3 Nephi 14:25, 3 Nephi 14:27, 3 Nephi 18:13, and 3 Nephi 22:11.

The following verses indicated the presence of the terms, but did not provide any further description or comparisons: 1 Nephi 18:8–9, Mosiah 12:12 (wind); Mosiah 7:30 (whirlwind); Helaman 11:13, 17, Ether 9:30, 35 (rain); Mormon 8:29 (tempests); Ether 2:20, Ether 3:2 (floods).

The following remaining verses are useful for comparisons of the various weather and/or hazard terminologies:

1 Nephi 12:4

> And it came to pass that I saw a mist of darkness on the face of the land of promise; and I saw **lightnings**, and I heard **thunderings**, and earthquakes, and all manner of **tumultuous noises**; and I saw the earth ~~and the rocks, that they rent~~ [that it rent the rocks] ; and I saw mountains tumbling into pieces; and I saw the plains of the earth, that they were broken up; and I saw many cities that they were sunk; and I saw many that they were ~~burned~~ [burnt] with fire; and I saw many that did tumble to the earth, because of the quaking thereof.

1 Nephi 18:13–14

> Wherefore, they knew not whither they should steer the ship, insomuch that there arose a **great storm**, yea, **a great and terrible tempest**, and we were driven back upon the waters for the space of three days; and they began to be frightened exceedingly lest they should be drowned in the sea; nevertheless they did ~~not~~ loose me [not].
>
> And on the fourth day, which we had been driven back, **the tempest** began to be exceedingly sore.

1 Nephi 18:21

> And it came to pass after they had loosed me, behold, I took the compass, and it did work whither I desired it. And it came to pass that I prayed unto the Lord; and after I had prayed **the winds** did cease, and **the storm** did cease, and there was a great calm.

1 Nephi 19:11

> For thus spake the prophet: The Lord God surely shall visit all the house of Israel at that day, some with his voice, because of their righteousness, unto their great joy and salvation, and others with the **thunderings** and the **lightnings** of his power, by **tempest**, by fire, and by smoke, and vapor of darkness, and by the opening of the earth, and by mountains which shall be carried up.

2 Nephi 6:15

> And they that believe not in him shall be destroyed, both by fire, and by **tempest**, and by earthquakes, and by bloodsheds, and by pestilence, and by famine. And they shall know that the Lord is God, the Holy One of Israel.

2 Nephi 26:5

> And they that kill the prophets, and the saints, the depths of the earth shall swallow them up, saith the Lord of Hosts; and mountains shall cover them, and **whirlwinds** shall carry them away, and buildings shall fall upon them and crush them to pieces and grind them to powder.

2 Nephi 26:6

> And they shall be visited with **thunderings**, and **lightnings**, and earthquakes, and all manner of destructions, for the fire of the anger of the Lord shall be kindled against them, and they shall be as stubble, and the day that cometh shall consume them, saith the Lord of Hosts.

2 Nephi 27:2

> And when that day shall come they shall be visited of the Lord of Hosts, with **thunder** and with earthquake, and with a great noise, and with **storm**, and ~~with~~ **tempest**, and with the flame of devouring fire.

Mosiah 7:31

> And again he saith: If my people shall sow filthiness they shall reap the **east wind**, which bringeth immediate destruction.

Mosiah 12:6

> And it shall come to pass that I will send forth **hail** among them, and it shall smite them; and they shall also be smitten with the **east wind**; and insects shall pester their land also, and devour their grain.

Alma 26:6

> Yea, they shall not be beaten down by the storm at the last day; yea, neither shall they be harrowed up by the **whirlwinds**; but when **the storm** cometh they shall be gathered together in their place, that **the storm** cannot penetrate to them; yea, neither shall they be driven with **fierce winds** whithersoever the enemy listeth to carry them.

Helaman 5:12

> And now, my sons, remember, remember that it is upon the rock of our Redeemer, who is Christ, the Son of God, that ye must build your foundation; that when the devil shall send forth his **mighty winds**, yea, his shafts in **the whirlwind**, yea, when all his **hail and his mighty storm** shall beat upon you, it shall have no power over you to drag you down to the gulf of misery and endless wo, because of the rock upon which ye are built, which is a sure foundation, a foundation whereon if men build they cannot fall.

Helaman 5:30

> And it came to pass when they heard this voice, and beheld that it was not a voice of **thunder**, neither was it a voice of a **great tumultuous noise**, but behold, it was a still voice of perfect mildness, as if it had been a whisper, and it did pierce even to the very soul--

Helaman 14:21

> Yea, at the time that he shall yield up the ghost there shall be **thunderings** and **lightnings** for the space of many hours, and the earth shall shake and tremble; and the rocks which ~~are~~ [is] upon the face of this earth, which ~~are~~ [is] both above the earth and beneath, which ye know at this time ~~are~~ [is] solid, or the more part of it is one solid mass, shall be broken up;

Helaman 14:23

> And behold, there shall be **great tempests**, and there shall be many mountains laid low, like unto a valley, and there shall be many places which are now called valleys which shall become mountains, whose height [thereof] is great.

Helaman 14:26-27

> And behold, thus hath the angel spoken unto me; for he said unto me that there should be **thunderings** and **lightnings** for the space of many hours.

> And he said unto me that while **the thunder** and **the lightning** lasted, and **the tempest**, that these things should be, and that darkness should cover the face of the whole earth for the space of three days.

3 Nephi 8:5-7

> And it came to pass in the thirty and fourth year, in the first month, ~~on~~ [in] the fourth day of the month, there arose a **great storm**, such an one as never had been known in all the land.
>
> And there was also a **great and terrible tempest**; and there was **terrible thunder**, insomuch that it did shake the whole earth as if it was about to divide asunder.
>
> And there were **exceeding~~ly~~ sharp lightnings**, such as never had been known in all the land.

3 Nephi 8:12

> But behold, there was a more great and terrible destruction in the land northward; for behold, the whole face of the land was changed, because of **the tempest** and **the whirlwinds** and **the thundering** and **the lightnings**, and the exceedingly great quaking of the whole earth;

3 Nephi 8:16–17

> And there were some ~~who~~ [which] were carried away in **the whirlwind**; and whither they went no man knoweth, save they know that they were carried away.
>
> And thus the face of the whole earth became deformed, because of the **tempests**, and **the thunderings**, and **the lightnings**, and the quaking of the earth.

3 Nephi 8:19

> And it came to pass that when **the thunderings**, and **the lightnings**, and **the storm**, and **the tempest**, and the quakings of the earth did cease--for behold, they did last for about the space of three hours; and it was said by some that the time was greater; nevertheless, all these great and terrible things were done in about the space of three hours--and then behold, there was darkness upon the face of the land.

3 Nephi 10:9

> And it came to pass that thus did the three days pass away. And it was in the morning, and the darkness dispersed from off the face of the land, and the earth did cease to tremble, and the rocks did cease to rend, and the dreadful groanings did cease, and all **the tumultuous noises** did pass away.

3 Nephi 10:13–14

> And they were spared and were not sunk and buried up in the earth; and they were not drowned in the depths of the sea; and they were not burned by fire, neither were they fallen upon and crushed to death; and they were not carried away in **the whirlwind**; neither were they overpowered by the vapor of smoke and of darkness.
>
> And now, whoso readeth, let him understand; he that hath the scriptures, let him search them, and see and behold if all these deaths and destructions by fire, and by smoke, and by **tempests**, and by **whirlwinds**, and by the opening of the earth to receive them, and all these things are not unto the fulfilling of the prophecies of many of the holy prophets.

Ether 2:24–25

> For behold, ye shall be as a whale in the midst of the sea; for the mountain waves shall dash upon you. Nevertheless, I will bring you up again out of the depths of the sea; for **the winds** have gone forth out of my mouth, and also **the rains** and **the floods** have I sent forth.
>
> And behold, I prepare you against these things; for ye cannot cross this great deep save I prepare you against the waves of the sea, and **the winds** which have gone forth, and **the floods** which shall come. Therefore what will ye that I should prepare for you that ye may have light when ye are swallowed up in the depths of the sea?

Ether 6:6

> And it came to pass that they were many times buried in the depths of the sea, because of the mountain waves which broke upon them, and also **the great and terrible tempests** which were caused by the fierceness of **the wind**.

The events or items that are obviously mutually exclusive throughout are thunder and lightning with each other and everything else. One important distinction clear from the passages is that thunder and "tumultuous noises" are clearly not the same thing. Whirlwinds are also essentially exclusive except that they occur in conjunction with mighty or fierce winds, which of course is not surprising. The principal reason for this analysis is to get a better delineation of the terms 'storm' and 'tempest.' When reading the Book of Mormon description of the destruction, it identifies both a storm and a tempest. It is important to verify that they were separate events, as they may delineate separately generated hazards. The principal questions that need to be considered from the Book of Mormon textual language are:

1. Does the term "storm" inherently include rain?
2. What are the apparent definitions of "storm" and "tempest"?

Webster's Dictionary (2013) defines a "storm" as "a disturbance of the atmosphere marked by wind and usually by rain, snow, hail, sleet, or thunder and lightning" and defines "tempest" as "a violent storm." Webster's Dictionary (1828) defines a "storm" as a "violent wind. It has primarily no reference to a fall of rain or snow. But as a violent wind is often attended with rain or snow, the word 'storm' has come to be used, most improperly, for a fall of rain or snow without wind." There is nothing in the text of the Book of Mormon that is inconsistent with the definitions found in Webster's. A 'storm' is implied to include rain, as rain is never used in conjunction with or in addition to the word 'storm' in the Book of Mormon. It is only apparently clarified when hail is involved, which would be reasonable considering that hail is probably not a common event. In the Book of Mormon, use of the term 'tempest' is also consistent with Webster's as 'tempest' is often associated with those items consistent with a violent storm such as thunder, lightning, and fierce wind (ships "driven" back, etc.).

Conclusion

A volcano-only scenario for the 3rd Nephi disaster is not viable to account for the description given in the Book of Mormon as volcanic earthquakes are simply not of the magnitudes necessary to account for the events and level of damage described in the Book of Mormon. In addition to a volcano, a large regional earthquake will be necessary to account for the level of damage described.

A storm involving precipitation cannot be ruled out based on the descriptions and text of the Book of Mormon. The usage of the term “storm” is not inconsistent with the current usage of the term, which typically involves precipitation.

Chapter 7

No-Hurricane Scenario and the "Great Storm"

As has already been touched upon in chapter 6, some previous writings have asserted that the "great storm" mentioned in 3rd Nephi 8:5 can be explained without a hurricane, while Sorenson has suggested that a hurricane might be involved.

Hurricanes are not unknown in the Isthmus of Tehuantepec, although they are not as common as in other areas in the Gulf of Mexico. The Isthmus is further south than most hurricane tracks and it is shielded by the Yucatan Peninsula from west-bound hurricanes. According to the NOAA Historical Hurricane Tracks database, there have been seven H1 hurricanes, one H2 hurricane, and one H3 hurricanes make landfall in the Isthmus since 1842. Based on the current historical data, a powerful hurricane is an unusual event in the Isthmus. Figure 57 shows all the known tropical storm and hurricane tracks going back to 1842.

In evaluating a 3rd Nephi scenario that lacks a hurricane, the first place we need to look for illumination on this issue is the Book of Mormon text itself. From 3rd Nephi 8:5–6, it is clear that there were two events, a "great storm, such an one as never had been known in all the land" and "also a great and terrible tempest." The prophecy of Zenos mentions only "tempest" (1 Nephi 19:11). Samuel the Lamanite cites the plural "great tempests" (Helaman 14:23) and makes no mention of a storm; however, later in Helaman 14:27 he refers only to a single "tempest."

Third Nephi 8:17 refers to the fact that the whole earth was deformed because of the "tempests," again in the plural, while 3rd Nephi 8:12 refers to the same event in the singular as a "tempest" and again in the singular in 3rd Nephi 8:19. 3rd Nephi 10:14 again refers to "tempests."

The situation is less than clear. The most consistent interpretation is that there was a tempest and a storm, which appeared to be separate. However, the storm was also referred to as a 'tempest' and as part of a plural 'tempests,' so there were still two separate events. It appears that Samuel the Lamanite identifies both the great tempest and the great storm as "tempests," with only one tempest actually changing the face of the land.

While there are arguments for and against identifying the "great storm" as a hurricane, the description of events by Zenos (where "storm" is not used) or by Samuel (where "storm" is also referred to as a "tempest") may better classify the "great storm" as part of the volcanic eruption, as perhaps a description of the initial mushroom ash cloud and subsequent airborne ash distribution combined with the initial blast shock wave, wind, and precipitation. Based on the assertion that the tempest(s) were one of the agents in the changing of the face of the land northward, it is fairly certain that the "great and terrible tempest" referred to volcanic pyroclastic or surge flows.

Figure 57. Tropical storm and hurricane tracks since 1842. Light blue is tropical/subtropical depression; green is tropical/subtropical storm; yellow is H1 level hurricane; orange is H2 level hurricane; red is H3 level hurricane; pink is H4 level hurricane; purple is H5 level hurricane (http://csc.noaa.gov/hurricanes/#, 2014, NOAA)

Arguments against the "great storm" being a hurricane are:

1. The Book of Mormon does not say anything about rain as an element of the destruction and there is reference to "exceeding dry wood." This issue was dealt with in chapter 6, and does not appear to be a strong argument;
2. Various cities were burned, which is incompatible with a hurricane;
3. The seasonality of a hurricane does not fit known meteorology.

Burning of Cities during a Hurricane

It would seem like common sense to assume that cities would not be subject to burning in the presence of a hurricane because of the associated precipitation. In this case, common sense is contrary to the historical record. Edward Bryant (2005, 210) recounts that a Tokyo earthquake known as the Great Kanto Earthquake on September 1, 1923, immediately collapsed over a half million buildings and created a tsunami. However, these events were not responsible for the ultimately large death toll, because many of the collapsed buildings consisted of lightweight materials. The deaths resulted from the fires that immediately broke out in the cities of Tokyo and Yokohama, and raged for three days, destroying over 50% of both cities. The outbreaks of fire were minor to begin with, but they occurred throughout both cities in large numbers, mainly because the earthquake occurred at lunchtime when many open fires were being used for cooking. Within a half hour, over 200 small fires were burning in Yokohama and 136 were raging in Tokyo. The spread of fire was aided initially by strong tropical cyclone winds, as a cyclone had arrived the previous day.

Sorenson (2013, 648) also cites an event in Yucatan, where a hurricane destroyed houses whose straw roofs caught on fire causing them to burn in the high winds.

Another reason why one cannot rule out a hurricane because of precipitation issues is due to the fact that Gulf of Mexico hurricanes typically have a drier southern side. Figure 58 shows the rainfall pattern for Hurricane Claudette, which would be a typical for an Atlantic/Gulf of Mexico hurricane.

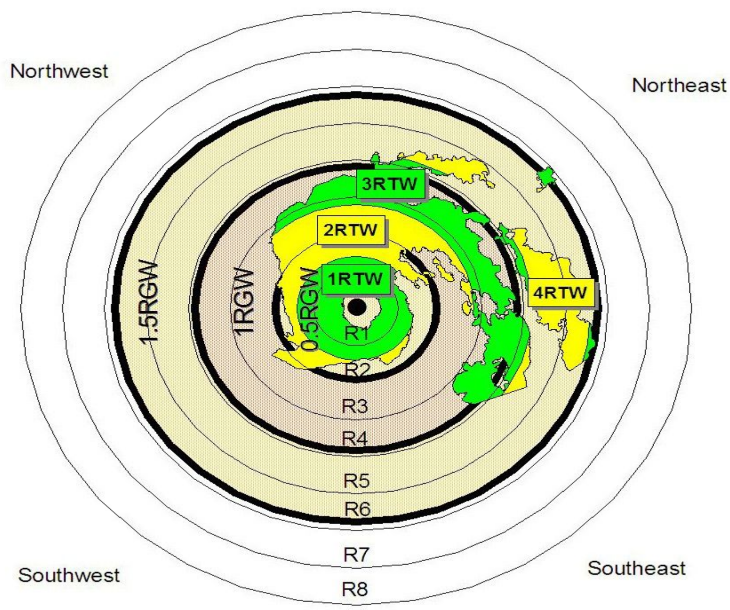


Figure 58. Rain shield and grid of Hurricane Claudette (2003) at the time of landfall (Matyas, 2007)

There are also hurricanes that are referred to as "dry hurricanes" at landfall because their winds arrive far ahead of the precipitation. One good example is Hurricane Hugo where rains arrived two days after the main hurricane winds. It has been roughly correlated that most "dry hurricanes" have a higher forward speed than average. The question of the speed of a hurricane in relation to precipitation also raises the issue of the timetable given in 3rd Nephi with regards to the "great storm." It was indicated that the storm ended within roughly 3 hours, perhaps a little longer. Although we are not certain that the term 'hour' corresponds to a 60-minute hour (see chapter 5), for purposes of analysis it would be useful to assume that the hour was measured the same as today. The width of a hurricane averages 100 miles in diameter (from hurricane wind edge to hurricane wind edge) but can be as small as 80 miles. The Isthmus of Tehuantepec is roughly 130 miles across; one might consider a narrower width of the area that was significantly populated at the time to perhaps 90 miles.

Table 4 shows data generated by the National Oceanographic and Atmospheric Administration (NOAA), which maintains a database of historic hurricanes and their characteristics called HURDAT. Considering that the Isthmus of Tehuantepec is located at a latitude of 18 degrees north, the average speed of a hurricane would be 10.8 miles per hour. The highest speed in the database is for an unnamed Tropical Storm #6 in 1961. It got caught up by a midlatitude trough over the midatlantic states and went speeding off northeastward over Maine and New Brunswick at a maximum speed of 69.75 mph. The fastest hurricane in the record was Emily in 1987, whose maximum speed reached 68.65 mph as it raced over the North Atlantic.

Table 4. Average Speed of Hurricane (NOAA, 2014)

Forward speed of Atlantic hurricanes averaged by 5 degree latitude bins

Latitude bin	Speed			No. Cases
	km/hr	knt	mph	
0°- 5°N	25.9	14.0	16.1	186
5°-10°N	22.0	11.9	13.7	4678
10°-15°N	19.2	10.4	11.9	7620
15°-20°N	17.4	9.4	10.8	7501
20°-25°N	17.5	9.4	10.8	8602
25°-30°N	20.1	10.8	12.5	6469
30°-35°N	27.1	14.6	16.9	3397
35°-40°N	39.0	21.0	24.2	1120
40°-45°N	49.3	26.6	30.6	264

45°-50°N	51.5	27.8	32.0	34
50°-55°N	51.4	27.8	32.0	15
55°-60°N	55.8	30.1	34.7	1

Considering the size of a hurricane from landfall to dissipation (when the trailing edge passes), then the total distance of passage for a smaller sized hurricane would be 170 miles over the Book of Mormon population in the Isthmus of Tehuantepec. At an average speed of 10.8 miles per hour, a smaller hurricane would take 16 hours to pass. Assuming the speed of the fastest hurricane recorded, the travel time across the Isthmus would be 2.5 hours. Since we don't know exactly what the author in the Book of Mormon meant by the start time of the great storm, one might consider using the arrival and departure of precipitation as the length of time for the storm, which would give an effective travel distance of 130 miles. With that diameter, assuming a passage time of perhaps 3.5 hours, than the hurricane would have had a travel speed of 37 miles per hour.

Whatever the calculation, if a hurricane did in fact impact the Isthmus of Tehuantepec, it would have had to have been a fast moving hurricane to pass through the area within a 3-hour window.

Seasonality

According to the current activity of hurricanes, a hurricane in late March or early April (the theoretical time of the 3rd Nephi disaster) would have been a very unusual event. Climatologically speaking, approximately 97% of tropical cyclones that form in the North Atlantic develop between the dates of June 1 and November 30. The NOAA database shows that out of a total of 2580 there were only 8 tropical storms or hurricanes that occurred prior to the month of May for the years 1851–2013.

While we can try to use current data to evaluate current hurricane behavior, one cannot definitively say that March or April hurricanes were as unusual in the remote past. According to Murnane and Lui (2004, 4, 52) tropical cyclone activity is known to vary over time scales that range from days to millennia. One of the highest frequency variability is intraseasonal changes in tropical cyclone activity. The Madden-Julian Oscillation (MJO) is the best known, though incompletely understood, source of tropical atmospheric variability on intraseasonal time scales. Active phases of the MJO are associated with more frequent tropical cyclone formation. Once a tropical cyclone forms, other types of intraseasonal climate variability can have an impact on tropical cyclone track. For example, the strength and phase of the North Atlantic Oscillation (NAO) appears to influence preferred hurricane tracks in the North Atlantic Ocean. On interannual time scales, the El Niño-Southern Oscillation (ENSO) appears to be the dominant factor controlling tropical cyclone activity. ENSO alters tropical cyclone activity through its effects on atmospheric features (for example, vertical wind shear) and on ocean temperatures. Additional factors such as the phase of the Quasi-Biennial Oscillation and regional sea level pressure anomalies are correlated with tropical cyclone activity and appear to produce interannual variations in tropical cyclone activity. Whether these climatological phenomena existed at the time of the 3rd Nephi disaster as they do now, or even existed at all cannot yet be definitively answered.

There is also a branch of science called paleotempestology that uses a variety of techniques to look at backwater depositional evidence of paleo hurricanes. Although I was unable to locate any studies within the Isthmus of Tehuantepec, studies along the Gulf and Atlantic states reveal that distinct millennial-scale variability exists in catastrophic hurricane activity along the Gulf Coast, with a hyperactive period from 1450 BC to 950 AD (Lui, 2004). Even if paleotempestology studies were performed in the Isthmus area it is highly unlikely that they could give a precise year that a particular hurricane occurred, and it is probably impossible to determine the month.

3rd Nephi Requirements

When looking at each and every characteristic of the disaster in 3rd Nephi, all characteristics can be explained by phenomena other than a hurricane. It is clear however that certain elements of the disaster would have been made worse by a hurricane, namely hurricane spawned tornados (whirlwinds), thunder and lightning, and flooding related hazards including volcanic lahars.

"Great Storm" Possibilities

We are still left with the possibilities of the great storm being (1) a rare early season, fast moving hurricane, (2) a volcanic eruption coupled with some sort of lower grade local storm, or (3) a volcanic eruption itself (perhaps coupled with volcano-triggered precipitation).

With regards to the volcanic eruption, it is notable that the persons who witnessed the 1793 eruption of the San Martín volcano in the Isthmus initially thought it was a thunderstorm, since heavy clouds covered the mountain and thunderstorms were not uncommon in the area (Espíndola, 2010). Perhaps that is why the 3rd Nephi witnesses considered it a storm simply because that's what it looked like when it started out. If there was in fact a local ongoing storm at the time of the eruption, the eruption itself might not have been visible as separate from the storm.

The separate references to "tempest" seem to be consistent with a pyroclastic flow or ash event, as tempests are associated with high winds and they were contributors to the actual reshaping of the topography according to 3rd Nephi. Lacking a hurricane or local storm, the most reasonable explanation that squares with all of the Book of Mormon text is that the "great storm" was the elevated airborne ash mushroom with its accompanying thunder and lightning, with the "tempest(s)" also referring to the volcanic phenomena occurring at the ground level such as ash surge or pyroclastic flows.

"Never Had Been Known in All the Land"

A final point that requires discussion is the moniker used to describe the great storm, namely that it had "never had been known in all the land." For a Book of Mormon chronicler to state that it "never had been known" there must be some presupposition that there may have been records kept of some storm events. It is hard to put that kind of statement in a historical context, as it may be limited to the lifetime of the chronicler or back a few generations by oral history. It would not be expected that there were any written records of detailed meteorological standards of storms in Book of Mormon times, so the scope of this term may need to be treated with some latitude.

The statement can be interpreted that it was perhaps the biggest storm that had been witnessed, or that the type of storm never had been witnessed, or perhaps both. A strong hurricane certainly could meet that requirement as Isthmus hurricane frequency (based on current records) does not appear to be great (9 in 171 years); however, the hurricane intensities are consistently low when they do occur.

With the current data that we have on volcanic activity, this statement also seems to be applicable to volcanic eruptions in the Isthmus before 30 AD (with the caveat that the data is no doubt incomplete with regards to documentation of historic volcanic eruptions). For all volcanoes that are north of Guatemala City and south of Mexico City, using the Smithsonian Institution Global Volcanism Program data and excluding any eruption that has a data range that could place the eruption after 30 AD, the eruptions previous to that date are:

San Martín	710 BC
El Chichón	500 BC
Pico de Orzaba	730 BC
Popocatépetl	1815 BC
Chichinautzin	825 BC
Tacana	930 BC
Atitlán	870 BC
Acetenango	185 BC
Fuego	1505 BC

It is possible that some of the eruptions that were excluded could have occurred not much before 30 AD; in that case, the size and extent of the eruption may be what the 3rd Nephi chronicler was referring to "as never had been known in all the land."

Conclusions

An analysis of the "great storm" in relation to whether a hurricane is involved or not is not conclusive either way. Although an early season, fast moving hurricane would be rare, it is not outside the realm of possibility. A volcanic eruption alone or in conjunction with a local storm would seem to square reasonably with the Book of Mormon text as well.

Chapter 8
Multiple-Volcano Scenario

Various Internet postings and discussions have asserted that multiple concurrent volcanic eruptions would be necessary to sufficiently explain 3rd Nephi events. These all seem to assume that volcanic activity has to account for all of the destruction under the Volcano-Only scenario. They have asserted that because of the geographic size of the Sorenson model of the Book of Mormon area that more than one volcano is needed. Recent eruptions such as the 1793 San Martín eruption have demonstrated that one volcanic eruption centrally located in the Isthmus has sufficient ashfall dispersion to blanket most or all of the land northward and land southward, so the 3rd Nephi description of darkness does not require multiple volcanic eruptions. Even a volcano that is not centrally located could provide ashfall dispersion similar to a centrally located volcano if wind conditions were right. The ground destruction described in 3rd Nephi does not require multiple volcanic eruptions either, as it has been established that a regional earthquake is necessary in addition to a volcano to adequately account for the ground destruction.

However, it is certainly possible that the 3rd Nephi volcanic activity could have involved more than one volcano. Concurrent eruption of volcanoes is a somewhat rare event, and in the case of the Book of Mormon descriptions, all eruptions would have to start and end within a 3-day window.

Interaction between eruptions of separate volcanoes is a documented event (Miklius and Cervilli, 2003; Gudmundsson and Andrew, 2007). The phenomenon of earthquakes triggering volcanic eruptions is clearly established, and in one instance the eruption of two volcanoes was triggered simultaneously in Kamchatka (Zobin and Levina, 1998). On January 11, 2013, four volcanoes on the Kamchatka peninsula were observed simultaneously erupting (Kamchatka VERT, 2013). The Kamchatka volcanoes are not linked by common magma chambers, so their eruptions are geologically independent of each other.

While not an essential element of the 3rd Nephi description, multiple simultaneous eruptions would no doubt increase the ash cloud “mists of darkness” event. It would also increase the potential geographic area where certain cities may be located that experienced destruction due to volcanic events. It is a theory that will be difficult to verify, as it is difficult to pinpoint historical eruptions into a given century, let alone a 3-hour period on a particular day. In any event, it can be left open as a possibility based on known volcanic behavior.

Chapter 9
Earthquake and Volcano Interaction

Major tectonic earthquakes have long been linked to the triggering of volcanic eruptions, and evidence increasingly shows a mechanical relationship between these events (see Hill et al., 2002, and references therein). Scientific descriptions of volcanic eruptions concurrent with large earthquakes date back at least to the 19th (Darwin, 1840) and early 20th centuries (Rockstroh, 1903). The volcanoes Cordón Caulle and Puyehue erupted in Chile just one day after the large 1960 Valdivia earthquake (Barrientos, 1994; Lara et al., 2004).

Other prominent examples of volcanoes that have shown activity in association with major tectonic earthquakes are Mount Vesuvius and Mount Etna in Italy (Sharp et al., 1981; Nercessian et al., 1991; Marzocchi et al., 1993; Nostro et al., 1998; Gresta et al., 2005), the Santa Maria volcano in Guatemala (Rockstroh, 1903; Williams and Self, 1983; White and Harlow, 1993), the New Hebrides (Blot, 1976), various volcanoes in Japan (Koyama, 2002), Alaska (Sanchez and McNutt, 2004), Kamchatka (Walter, 2007), Mount St. Helens in the US (Lipman and Mullineaux, 1981), volcanoes in Iceland (Gudmundsson and Andrew, 2007), and Kilauea and Mauna Loa in Hawaii (Swanson et al., 1976; Lipman et al., 1985; Walter and Amelung, 2006).

A worldwide detailed study of volcano and earthquake interactions was completed by Egger and Walter in 2009. They determined some patterns that apply to the 3rd Nephi situation:

1. Volcanic eruptions can be triggered within seconds of an earthquake event. Most volcanic activity occurs on the same day as the earthquake.
2. The highest correlation of earthquakes triggering volcanic eruption was around the Pacific Ring of Fire (volcanoes surrounding the Pacific Ocean).
3. The most common events occur when the earthquake is near the volcano.
4. Before an earthquake, there is less regional volcanic activity in the years leading up to the earthquake; after an earthquake, there is more regional volcanic activity.

Paralleling these findings, the 3rd Nephi eruption and earthquake occurred virtually simultaneously. The Isthmus of Tehuantepec is part of the Pacific Ring of Fire. The San Martín volcano in the Tuxtla volcanic complex lies directly in the Veracruz fault system and the magma preferentially follows the fault zone to the surface. El Chichón and other volcanoes in the Isthmus are also on fault zones or immediately adjacent to fault zones. Sorenson (2013, 641–49) noted the increase in volcanic activity in the first century AD, and there also appears to be a decrease in general activity leading up to the 3rd Nephi event (see chapter 7).

It is very clear that the 3rd Nephi description of a regional earthquake coupled with a volcanic eruption is a recognized geologic phenomenon.

Chapter 10
Identification of a Regional Earthquake Fault Zone

As has been established, volcanic earthquakes alone cannot account for the earthquake intensity described in 3rd Nephi. When looking at the potential fault zones where a large magnitude earthquake might have taken place, the actual text of the Book of Mormon gives us some clues that will help in determining the probable regional location of the earthquake. It does not appear possible at this point to even conjecture what the specific individual fault movements were, but it should be possible to identify the most likely fault zone. In order to determine the location of the fault zone it is necessary to compare the earthquake effects with known Book of Mormon locations.

Surface Indication: Rupture/Cracking and Subsidence

The first geologic criterion to be evaluated is surface rupture or cracking. Deep earthquakes do not typically cause much surface rupture. In addition, observations of modern earthquake effects in the Isthmus have not shown areas of significant ground motion amplification at long distance. Therefore, references to surface ruptures would be expected in the fault zone for primary fault ruptures or immediately adjacent for secondary rupture features (i.e., liquefaction and lateral spreading). Where surface ruptures are identified, it should be indicative of a fault zone with shallow earthquake potential. Finally, it should be noted that strike-slip faults generally generate more types of surface rupture effects at the fault trace than other types of faults.

The following references in the Book of Mormon identify and describe the surface rupture and fractures that occurred because of the quaking of the earth:

1 Nephi 12:4

> … and I saw the earth ~~and the rocks, that they rent~~ [that it rent the rocks]; … and I saw the plains of the earth, that they were broken up;

1 Nephi 19:11

> … by the opening of the earth,

Helaman 14:21–22

> … and the rocks which ~~are~~ [is] upon the face of ~~this~~ [the] earth, which ~~are~~ [is] both above the earth and beneath, which ye know at this time are [is] solid, or the more part of it is one solid mass, shall be broken up; Yea, they shall be rent in twain, and shall ever after be found in seams and in cracks, and in broken fragments upon the face of the whole earth, yea, both above the earth and beneath.

3 Nephi 8:12–13 (in the land northward)

> … the whole face of the land was changed … And the highways were broken up, and the level roads were spoiled, and many smooth places became rough.

3 Nephi 8:18 (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.

What can be gleaned from these scriptures is that there was (1) widespread surface rupture and fracturing in the land northward, and (2) “the plains of the earth” were broken up.

A second earthquake surface feature is subsidence. Without quoting each scripture, the following scriptures refer to sinking of some sort:

1 Nephi 12:4 (cities sunk, no area identified); 3 Nephi 8:9, 9:4 (city of Moroni); 3 Nephi 8:14, (cities in the land northward); 3 Nephi 9:6–8, 4 Nephi 1:9 (various cities including Jerusalem); 3 Nephi 9:13 (persons sunk and buried); and 3 Nephi 8:13 (level roads spoiled).

It is important to note that subsidence can also occur on the flanks of a volcano during and after eruption, primarily from subsidence caused by emptying of the magma chamber, but this would only be a small local effect. Also, the burial of cities or persons should be differentiated from sinking, as the burial may have resulted solely from a volcanic effect or landslide. Similarly, references concerning the land northward to the changing of the “face of the land” and the land being “deformed” (3 Nephi 8:17) could be exclusively caused by the effects of a volcanic eruption and/or landslide, even though the quaking of the earth is also mentioned.

Similar to surface rupture, subsidence generally occurs within the fault zone or immediately adjacent, with some subsidence possible at distance due to liquefaction or lateral spreading. There are two cities mentioned in relationship to subsidence that have other corroborative geographical ties. The city Moroni was located “by the east sea” and sank into the sea, and is located in the land southward. It has been suggested that the destruction of Moroni could have been caused by a storm or hurricane surge (Sorenson, 1985,322), presumably with the sinking being referred to in the Book of Mormon being interpreted as beach erosion caused by the surge. Given the short duration of the storm (3 hours), a fast passage that would indicate a smaller hurricane, this explanation may not suffice even though hurricane storm surges have been documented to cause significant erosion in excess of 5 meters in the Gulf of Mexico where beach barrier spits or islands are involved (Stockdon, 2012, 11). Kowallis (1997, 162–65) has asserted that a tsunami may have been responsible for the sinking of the city of Moroni. Similar to a storm surge, a tsunami would have caused sinking by inundation erosion. The second city with scriptural references (under some textual interpretations) to sinking, Jerusalem, by corroborative geography from the Book of Mormon text according to the Sorenson model, is located far to the south in the land southward.

Indicators of the Location of the Fault Zone

As enumerated here and in previous chapters there are a number of conditions that the fault zone must meet:

1. The fault type must be capable of causing extensive surface rupture and fracturing, as well as subsidence, with the worst earthquake damage occurring in the land northward.
2. At least a portion of the fault zone must also be in the land southward or be located such that a large earthquake will cause significant damage in the land southward.
3. It must break up “the plains.”
4. It must cause subsidence in areas that would subject cities to burial (as some cities were both sunk and buried), namely by eruptive volcanic deposition or landslide/mass movement.
5. The earthquake must have occurred in or near a populated area, or had significant effect in a populated area.

There are an additional number of preferential conditions that, if met, would provide strong indications of the fault zone where the 3rd Nephi earthquake took place:

1. The fault zone is capable of causing subsidence in the city of Moroni.
2. The fault zone is capable of causing subsidence in the city of Jerusalem.
3. Damage from the earthquake can be observed from a location within the land of Bountiful, and have a reduced damage level in Bountiful.
4. A volcano capable of causing the 3rd Nephi volcanic damage is located in or immediately adjacent to the fault zone.
5. The fault zone is capable of causing a tsunami in the east sea.
6. It must cause subsidence in areas that would subject cities to be covered quickly with water.

Best Fit Fault Zone

There are only two regional fault zones in the Isthmus, the Pacific Coast Subduction Zone and the Veracruz-Polochic/Motagua Strike-Slip Fault Province. The Veracruz-Polochic/Motagua province is divided into two segments, the Veracruz fault system and the Polochic/Motagua fault system. The two segments are separated (at the south end of the Veracruz and the north end of the Polochic/Motagua) by a “step-over area” where the fault systems have an offset in alignment. In applying the criteria above, the best-fit scenario appears to be strike-slip movement in the Veracruz-Polochic/Motagua Strike-Slip Fault Province, with the principal movement occurring in the Veracruz fault system.

Specifically, the criteria that is exclusively met by the Veracruz-Polochic/Motagua system is that strike-slip faults create more surface rupturing than the deeper Pacific Coast faults. In addition, the Veracruz fault system is located in the Gulf Coastal Plain, which stretches from Veracruz south to Tabasco and is the only significant plain located in the Isthmus of Tehuantepec. The Pacific Coastal plain is a narrow band from 5 to 20 kilometers in width; it was only lightly populated compared with the Gulf Coastal Plain. The other preferential conditions that are exclusively met by the Veracruz-Polochic/Motagua system are the ability to cause subsidence in the cities of Moroni and Jerusalem, the ability to cause damage observable from the city of Bountiful, a volcano that is in the fault zone (San Martín), and the ability to cause a tsunami in the east sea.

Earthquake Scenario

Finally, it will be useful to model a worst-case earthquake scenario for the Isthmus fault systems in order to project probable zones of Mercalli intensity for each fault system and see whether the results will also identify the probable fault zone. It is necessary to utilize the Mercalli intensity scale for pre-instrument historical earthquakes as it is based on the damage reports on the surface, not measurement by seismic instrument. It is an intensity scale that measures *felt intensity* not *monitored intensity*, based on eyewitness reports, felt shaking, and observed damage. When one is trying to 'recreate' an historic earthquake based on eyewitness reports, which is what we have in the Book of Mormon, it is the appropriate scale to use. Unfortunately, much of the description of damage in the Book of Mormon is regional damage with general damage descriptions, and because we don't have any specific locations for most of the cities mentioned in 3rd Nephi, we do not have geographic pinpoints to use. The only identifiable cities to work with under the Sorenson model are the cities of Zarahemla, Moroni, Bountiful, and Jerusalem, of which locations for Moroni, Bountiful, and Jerusalem are not really all that exact because more than one archeological location within a restricted area could meet the geographical descriptions mentioned in the Book of Mormon. We are principally dealing with eyewitness descriptions of destruction in larger areas like the "plains" and the "land northward" and the "land southward" that we can reliably identify. Be that as it may, there is enough information to determine which of the fault systems was the likely source of the earthquake, and we can model each of the faults to characterize the earthquake intensities for each fault system.

Earthquake modelling is not an exact science, and is highly dependent on the utilization of actual spatially concentrated seismic data collected over long periods of time. Faults like the San Andreas in California have had extensive data collection and detailed geologic mapping with millions of dollars spent to develop accurate models; such is not the case on the Veracruz fault or other faults in southern Mexico and Guatemala.

As this is just a general analysis, it is not necessary to have too much specificity on damage locations—some assumptions can be made. The first assumption is that the analysis will assume that the earthquake could have occurred anywhere along the entire Pacific Coast subduction fault system. In that way we should be able show the potential effects for movement along any section. Only the Veracruz segment of the fault will be examined as it is the only segment that is within the land northward. Again, the entire length of the segment will be looked at. The second assumption is that earthquakes did not occur simultaneously on both fault systems. While that is always a possibility, a rule of thumb for aftershocks from adjacent faults is that the aftershocks occur within the distance of the length of the initial fault rupture. Since the distance between the two fault systems ranges between 100 and 200 km, it would require a 100 km rupture surface on one or the other faults to trigger aftershocks. While that is definitely possible, the model is an attempt to identify the first or primary cause of the earthquake. The third assumption is that the depth of the earthquake is at an intermediate depth, in the range of 25 to 35 km, and that the time duration of the earthquake is the average for southern Mexico. Both of these parameters can affect the damage extent of the earthquake, the depth of the earthquake is a depth that seemed reasonable, especially for the strike-slip type of earthquake event. The attenuation factors we will need to utilize for southern Mexico were developed using a combination of data from multiple earthquakes, so some extent of averaging for the time duration of the earthquake is necessary.

1. Attenuation formula

The principle of earthquake attenuation is that the intensity of the ground shaking by an earthquake decreases as one gets farther away from the fault. There are exceptions to that premise when there are unique soil and sediment situations that can amplify ground shaking. Those amplifications are looked at on a case-by-case and geographical area basis. The attenuation of an earthquake is affected by the type of rock that the seismic waves pass through. There are general attenuation formulas, but it is better to use formulas developed based on data from a particular region. As one looks at more detailed data for smaller and smaller areas, these attenuation formulae can become quite complex. For the purposes of this exercise, given that the analysis is going to be regional, a simple regional formula will be used.

In 1988, Mario Chavez and Raul Castro derived attenuation formulas to predict the attenuation of Modified Mercalli Intensity (I) with distance (D) for Mexican earthquakes:

$\text{In } I = B_o + B_1 \text{ In } (D/D') + B_2 (D-D') + B_3 \text{ In } M_s$

$\text{In } I = B_o + B_1 \text{ In } (D/D') + B_2 \text{ln } (D-D') + B_3 \text{ In } M_s$

M_s is the earthquake surface-wave magnitude, D and D' are distances related to the maximum intensity (I) mapped for an earthquake. The coefficients B_i, i = 0, 1, 2, 3 were obtained by utilizing a least-square method from the information contained in the intensity maps of 32 earthquake events. The events were classified in three groups according to their epicentral location, focal mechanism, and depth. The three groups are the Mexican Pacific subduction-zone intermediate-depth earthquakes, the south-central Mexico intermediate-depth earthquakes, and the shallow crustal events along the Trans-Mexican Volcanic Belt. For the profiles in the Isthmus, the Veracruz and the Polochic/Motagua fault segment earthquakes were considered to be equivalent to the south-central Mexico earthquakes.

For this model, an earthquake that would generate a magnitude of 11 was assumed. This level would be comparable to some of the worst earthquakes documented in modern times. Graphs developed by Chavez and Castro for some standard earthquakes were used to extrapolate the following attenuation profiles and zones:

Pacific Coast Subduction Zone earthquake

Mercalli Intensity	Distance from fault (km)
11	0
10 to 11	0-7
9 to 10	7-22
8 to 9	22-36
7 to 8	36-79
6 to 7	79-139
5 to 6	139-172
4 to 5	172-307

Veracruz and the Polochic/Motagua earthquake

Mercalli Intensity	Distance from fault (km)
11	0-6
10 to 11	6-14
9 to 10	14-29
8 to 9	29-50
7 to 8	50-100
6 to 7	100-157
5 to 6	157-172
4 to 5	172-257

Figure 59 is a map showing the result along each fault line. The shaded area shows all areas that would have experienced a Mercalli intensity of 7 or higher. As previously discussed, a Mercalli intensity of 7 would cause considerable damage in poorly built or badly designed structures. On the Pacific Coast, the fault trace used was where most of the earthquakes appear along the subduction zone; some do occur further inland, but even moving the earthquake fault line inland 50 km would not affect the conclusion of the analysis.

Figure 59. Areas subject to Mercalli 7 intensity or higher for an 11 intensity earthquake at the fault line

2. Adjustment for soil and sediments subject to amplification

The characteristics of geologic material at or just beneath the surface is a critical factor affecting earthquake shaking intensity. Deep, loose soils tend to amplify and prolong the shaking. If any of these types of soils are located at or relatively near a regional fault system, this would also be an additional indicator of the 3rd Nephi regional fault system. The worst soils are the loose clays and filled areas. The type of rock that least amplifies the shaking is granite. I was unable to locate any calculations in the Isthmus area of amplification due to the soil types. An area in the United States that has been intensely studied with regards to soil amplification is the San Francisco Bay area, which seems to have similar characteristics (strike-slip fault, muds, and clays) as the Isthmus. Factors in the San Francisco area have been determined by actual measurements that indicate the added factor of intensity when an earthquake occurs in a particular soil type (Perkins and Boatwright, 2010). The increment factors identified in San Francisco based on the type of soil/sediments are:

Material Properties	Predicted Intensity Increment Increase
Clay and silty clay, very soft to soft	2.4
Clay and silty clay, medium to hard	1.8
Sand, loose to dense	1.6
Sandy clay-silt loam, interbedded coarse and fine sediment	1.4
Sand, dense to very dense	1.1
Gravel	0.7

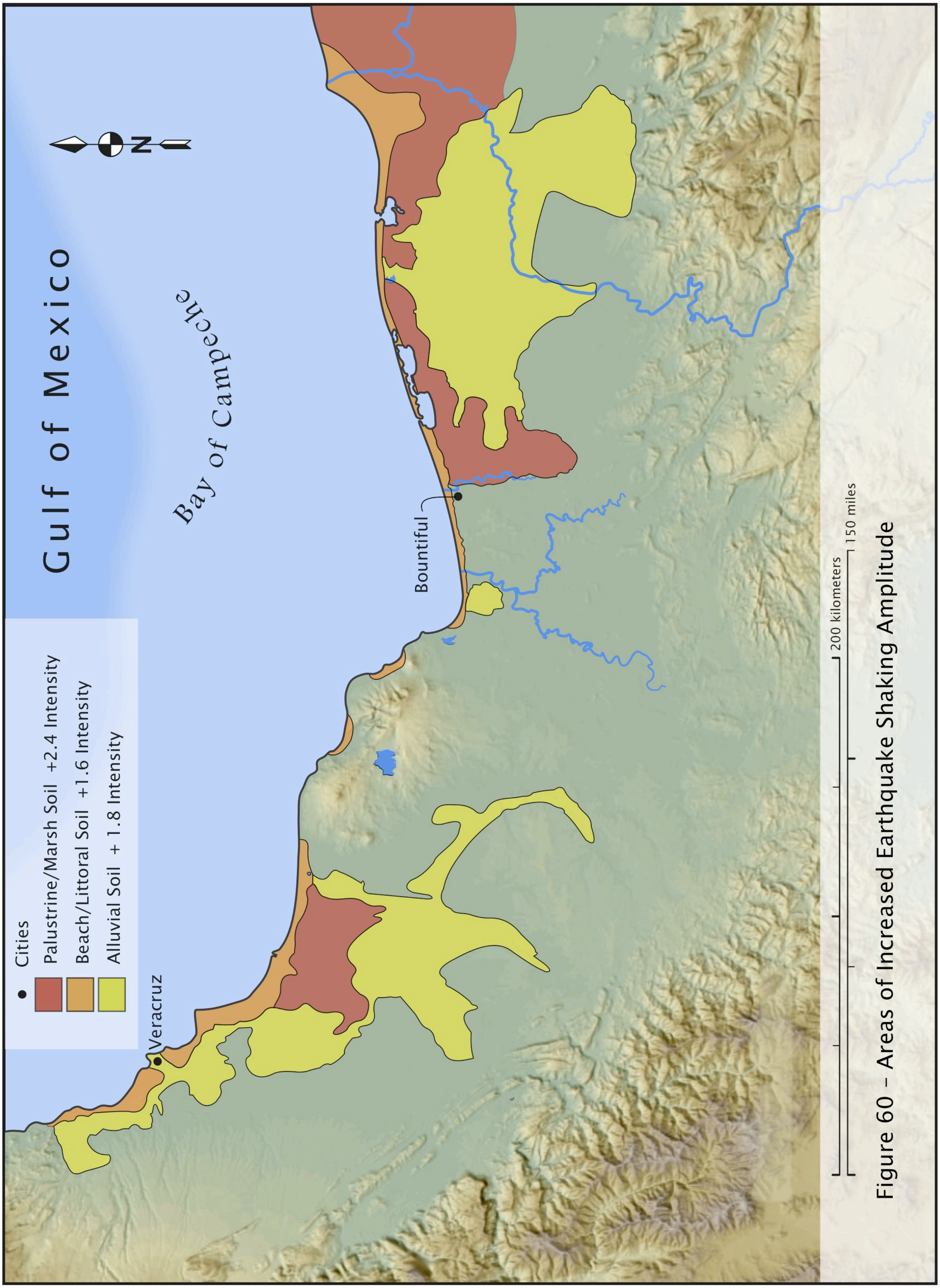


Figure 60 – Areas of Increased Earthquake Shaking Amplitude

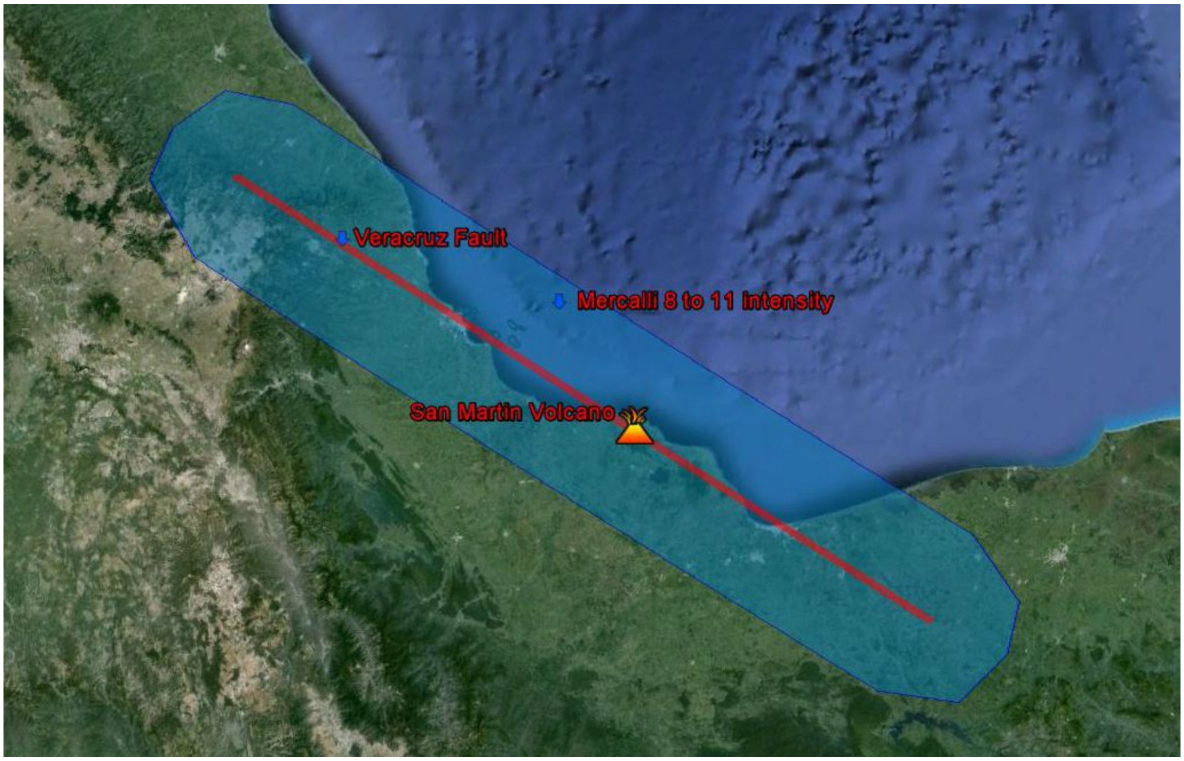


Figure 61. Areas subject to Mercalli 8 intensity or higher for an 11 intensity earthquake at the fault line where most fissuring, subsidence, lateral spreading, liquefaction, and earthquake induced landslides would be expected.

Now that the Veracruz fault is determined to be the primary regional fault, it is appropriate to determine some general zones of damage. Figure 59 shows all areas that would have been subject to an earthquake intensity of 7 or greater without local amplification; these would be the areas that would have significant or complete structural damage. Generally speaking, for most large earthquakes, the surface damage (ruptures, fissuring, settlement, subsidence/elevation, lateral spreading, and liquefaction) occurs in areas subject to earthquake intensities of 8 or greater. In the case of landslides, larger landslides can generally be triggered by intensities greater than 8, smaller landslides with intensities greater than 7. Figure 61 shows the areas potentially subject to an intensity level of 8 or greater along the Veracruz fault. It is important to note that figures 59 and 61 use a center line for the fault entire fault system when in actuality, the fault system consists of multiple faults many of which do not occur on the center line. As a result, it must be recognized that the damage areas indicated in the figures could be expanded to the southwest or northeast if one of the faults on the edge of the system is the one that experienced the most movement. In strike-slip fault earthquakes, one earthquake event will typically include movement on many faults within the fault system. Figure 60 shows the areas of amplification of effects due to soil and/or sediment conditions, which can occur both inside and outside of the zones shown in figures 59 and 61. The factors shown in figure 60 indicate the increase in whatever earthquake intensity is already present, meaning that the factor added to the modelled earthquake intensity will be the actual earthquake intensity expected in the problematic soil areas.

Analysis and Conclusion

The Veracruz fault segment satisfies all of the necessary conditions given in the Book of Mormon as the primary earthquake fault system. It is a strike-slip fault, which typically generates surface ruptures, fractures, and subsidence. It is located in the land northward where the worst damage occurred. Part of the fault segment is in the land southward and could cause damage in the land southward. It is located on and adjacent to the coastal plains. It occurs in areas that had significant population at the time.

The Veracruz fault system also satisfies most of the preferential conditions. It has a major volcano sitting directly on the fault system, the volcano San Martín. It occurs within parts of the land of Bountiful. Part of the fault system sits under water in the Gulf of Mexico and could potentially generate a tsunami. It possibly could cause effects triggering subsidence in the city of Moroni. There are major rivers and some lakes and lagoons on or adjacent to the fault, which could quickly fill areas of subsidence. The only preferential criteria that does not appear to be met is the ability to cause subsidence in the city of Jerusalem (located near Lake Atitlán in the Sorenson model), as the intensity felt at a distance of 400 km from the southern reach of the Veracruz fault would not be enough to cause any direct subsidence (at a level III on the Mercalli scale), and although possible, would not be expected to trigger landslides at that distance and intensity. However, the destruction at the city of Jerusalem may have involved non-earthquake related events, so this condition is not critical.

The Veracruz fault segment is the 'best fit' for the primary location of the regional earthquake that occurred at the time of 3rd Nephi.

Chapter 11
A Textual Analysis of the Locations of Cities Identified in 3rd Nephi

Before attempting to compare the cities identified in 3rd Nephi with specific geographic locations, it is first prudent to analyze the text and the text structure to see what it might indicate with regards to location. In other portions of the Book of Mormon examined earlier the destruction is described by prophecy, vision, or, in the case of Samuel the Lamanite, the recounting of events conveyed by an angel. There are no specific cities identified in any of these other portions; there are however a few geographical references.

Nephi's Vision

1 Nephi 12:3–5 mentions that there were many cities, and that the mist of darkness was on "the face of the land of promise" and that later the "vapor of darkness" passed off from "the face of the earth," perhaps implying by use of the phrase "land of promise," as opposed to more generic terms, that there were cities in both the land northward and the land southward and that the darkness affected them. It also mentioned that Nephi saw "the plains of the earth" that were "broken up" and "cities that were sunk."

Prophecies of Zenos and Samuel the Lamanite

The prophecy of Zenos in 1 Nephi 19:10–12 contains no specific geographical references. The preaching of Samuel the Lamanite in Helaman 14:20–29 contains a generic reference to the "face of the earth," to "the face of the whole earth," and to "all the face of this land." It does mention that "many cities shall become desolate."

Location of Cities in Either the Land Northward or the Land Southward according to 3rd Nephi

1. Geographical clues from textual ordering, structure, and grouping

Third Nephi 8:8–10 initially identifies three cities and their method of destruction in this order:

Zarahemla
Moroni
Moronihah

After a series of "And" statements initiating those verses (common elsewhere in the Book of Mormon), 3rd Nephi 8:11 then makes a final "and" statement: "And there was a great and terrible destruction in the land southward." The next verse (v. 12) starts with the clause "But behold, there was a more great and terrible destruction in the land northward." Recognizing that verse breaks were not part of the original Book of Mormon translation, the implication is that verses 8–11 are part of one clause with a summary statement as to the destruction that had occurred in the land southward inclusive of those three cities. There are no further cities enumerated in the land northward in chapter 8, but just general references to cities in the land northward and the nature of their destruction (3 Nephi 8:12–18).

Using the Book of Mormon text and geographicial relationships, the Sorenson model has placed Zarahemla in the land southward. Moroni is also located along the borders of the east sea (Gulf of Mexico) in the land southward. As there is some question as to where Moroni might precisely be located along the east sea, the Sorenson model could accommodate Moroni along a stretch of the coast. A location for Moronihah is not identified, however, Sorenson thought that Moronihah should probably be in the vicinity of Jershon in the borders by the east sea based on the operational area of Moronihah in a military capacity, which area is also within the land southward and may lie fairly close to the boundary between the land southward and the land northward (Sorenson, 2000, 118).

In a textual structural parallel, when a voice was later heard among the inhabitants, there is a nearly verbatim recounting in 3rd Nephi 9:3–5 of 3rd Nephi 8:3–5, which also initially identifies the same three cities and their method of destruction, in the exact same order:

Zarahemla
Moroni
Moronihah

The voice (which later identifies itself as Jesus Christ, 3 Nephi 9:15) then goes on to list additional cities that were destroyed. One could make the argument that by parallel textual construction with 3rd Nephi 8:8–18, the additional cities listed would by inference be located in the land northward, essentially a geographically ordered list. Since 3rd Nephi 8:12 indicates that the destruction was much more extensive in the land northward, this would not be an unreasonable argument. However, one of these additional cities is Jerusalem, which, according to the Sorenson model, is located deep into the land southward somewhere in the vicinity of Lake Atitlán.

By looking carefully at the textual structure in 3rd Nephi 9, it becomes apparent that the listing of the cities is clearly based on primary groups derived from the type of destruction that the cities underwent; geographical order would only be a secondary grouping tier. All of the groupings are based on a different destructive hazard, although some of the groups consist of just one city, and some of the differences in destructive method are slight.

The groupings by destructive method (including additional descriptions from 3rd Nephi 8 where slightly different and applicable) are as follows:

- Burned with fire; “take fire”
  —Zarahemla
- “sink into the depths of the sea”; “caused to be sunk in the depths of the sea, and the inhabitants thereof to be drowned”
  —Moroni
- “earth was carried up upon the city”; “in the place of the city there became a great mountain”; “covered with earth, and the inhabitants thereof”; “buried up”
  —Moronihah

- "caused to be sunk, and the inhabitants thereof to be buried up in the depths of the earth"
  —Gilgal
- "caused to be sunk, and the inhabitants thereof to be buried up in the depths of the earth"; "waters have I caused to come up in the stead thereof"
  —Onihah
  —Mocum
  —Jerusalem
- "caused to be sunk, and made hills and valleys in the places thereof; and the inhabitants thereof have I buried up in the depths of the earth"
  —Gadiandi
  —Gadiomnah
  —Jacob
  —Gimgimno
- "caused to be burned with fire"; "did cause them (the inhabitants) to be burned"; "did send down fire and destroy them"
  —Jacob-Ugath
  —Laman
  —Josh
  —Gad
  —Kishcumen

In considering a secondary geographical ordering influence, and in evaluating how the record was created for 3rd Nephi 8, it may have been that Mormon (or another compiler at the time) utilized the list in the order as spoken by Jesus Christ in 3rd Nephi 9, with the first three cities being from the land southward, and then, when arriving at Gilgal in the recitation of cities, a probable city from the land northward, chose to give a general description of the destruction in the land northward, realizing that most of the cities listed were located in the land northward. The only possible way to make the geographic delineation by order consistent, since Jerusalem is the only city in this list that the Sorenson model identifies to be in the land southward, is to consider that there was perhaps a second historic Jaredite-based city called Jerusalem in the land northward.

2. Cities of Jacob-Ugath and Jacob

The great city of Jacob-Ugath and probably the city of Jacob were located in the land northward. Third Nephi 9:9 makes it clear that the inhabitants of Jacob-Ugath were the subjects of King Jacob, the same Jacob who was king of a secret combination that was forced to flee to the "northernmost part of the land"(3 Nephi 7:9–13).

In addition, although somewhat speculative, the use of hyphenated city names in the Book of Mormon seems to indicate that the second part of the city name is in fact the land where the city is located. For example, the city and land of Lehi-Nephi are located within the land of Nephi (Mosiah 7:1–4; 9:1–8). A group of people that changed religious (and presumably political) affiliation became known as the Anti-Nephi-Lehites, an identity that also became to be considered a place (Alma 25:1; Alma 27:2) that encompassed seven different lands and cities, all of which were part of the land of Nephi (and also part of the larger land of Lehi [Helaman 6:10]). The conversion of the name of the people to the name of an area seemed to follow after the kingdom was conferred to an individual who was also concurrently took on the name Anti-Nephi-Lehi (Alma 24:3), consistent with the practice in the Book of Mormon of place names corresponding to kings or leaders.

Since Jacob-Ugath is apparently part of the land of Ugath it is possible to extract more detail as to its geographical location from the Book of Mormon. Dr. Brian Stubbs, a Native American language linguist, indicated that Ugath is probably of Jaredite origin being derived from Ogath (Ether 15:8–11), with the "o" to "u" sound shift being a recognized, common historical linguistic sound shift (Stubbs, 2014). In the book of Ether a large battle took place between the armies of Coriantumr and Shiz near the "waters of "Ripliancum." As a result of the battle, the armies of Shiz fled southward before the armies of Coriantumr, ending up pitching their tents at a "place called Ogath," with the armies of Coriantumr pitching their tents by the hill Ramah, which the Nephites called the hill Cumorah. The Sorenson model identifies the location of the hill Ramah/Cumorah as the modern Cerro Vigìa, which is part of the Tuxtla Mountains where the San Martín volcano is located. By the description of the movement and locations of the armies, the location of Ogath (Ugath) is not too far south of Cerro Vigìa.

There are no other apparent examples of Nephite/Lamanite place names incorporating Jaredite place names other than Gilgal, which is of Biblical origin, but there are examples of Nephite/Lamanite personal names incorporating Jaredite place and personal names. Examples of this are: Ahah:Aha, Coriantor:Corianton, Coriantumr:Coriantumr, Corihor:Korihor, Kishcumen: Kishcumen, Morianton:Morianton.

The location of Jacob-Ugath is quite clearly in the land northward, speculatively in the vicinity just south of Cerro Vigìa. Since Jacob-Ugath is part of the northernmost part of the land it may indicate that the northernmost extent of the land northward may have been somewhere south of Veracruz.

3. Jaredite Place Names as a Location Indicator

As is apparent from even a cursory reading of the Book of Mormon, many of the place names are named after individuals, typically kings or other types of leaders. In addition, it has been recognized that some of the original Jaredite place names were utilized or at least recognized by the Nephites. It is clear from the text of the Book of Mormon that the Jaredite civilization was located in the land northward and at the narrow neck separating the land northward from the land southward, with perhaps some minor overlap into the land southward on the boundary.

Therefore, an analysis of the city names listed in 3rd Nephi chapters 8 and 9 with regards to Jaredite origination should provide us with some additional information as to cities that would likely be located in the land northward. Obviously, this is not considered definitive evidence, as it is possible that some of these cities (i.e., Moroni) took their names from an individual who had a Jaredite or Jaredite-derived name but may never have actually lived in the Jaredite lands.

The city name of Gilgal is directly referenced in Ether 13:27–30 as the valley of Gilgal. The name Jerusalem was known to the Jaredites from the teachings of Ether (see Ether 13). While not directly identified as Jaredite place names, some cities exhibit Jaredite linguistic patterns. John A. Tvedtnes (1973) prepared a phonemic analysis of Jaredite proper names and identified the following city names as being of Jaredite origin:

Moroni
Kishcumen

Tvedtnes identified the following city names of having at least some possibility of Jaredite origin:

Mocum
Gadiandi
Gadiomnah

Stubbs indicated that Onihah is probably of Jaredite origin being derived from Orihah (Ether 1:32), with the “r” to “n” sound shift being a recognized historical linguistic sound shift.

From a linguistic and textual standpoint, ten of the sixteen cities (Jacob-Ugath, Jacob, Jerusalem, Gilgal, Moroni, Kishcumen, Mocum, Gadiandi, Gadiomnah, and Onihah) could be located in the land northward or immediately adjacent to the land northward. The others, with the exception of Zarahemla, could also be located within or near the land northward based on textual analysis. This does not mean that all are located in the land northward, just that their location in the land northward would not be anomalous.

4. Land of Bountiful

The land of Bountiful is mentioned in 3rd Nephi 11:1 and is noteworthy because it was apparently one of the cities that was apparently spared from much of the destruction as it was a place where a “great multitude” gathered post destruction “round about the temple.” It must have been in an area where the destruction was visible as the people were “showing one to another the great and marvelous change which had taken place.” It is not known precisely how long after the destruction that the multitude was gathered, as it occurred “in the ending of the thirty and fourth year” and “soon after the ascension of Christ into heaven” (3 Nephi 10:18). This description also perhaps suggests that they were able to use the height of the temple to get a better view of things.

“Whole Earth” and “All the Land” Phrases

The phrases “whole earth” and “all the land” are utilized in various places in 3rd Nephi chapters 8 and 9. In general, the context appears to be that the “whole earth” is discussed in relation to both the lands northward and southward. “All the land” is sometimes used referring to either the land southward or the land northward, depending on the context, but also is used in a similar context as the “whole earth.” The understanding that these terms are commonly used referring to a limited geographical area typically encompassing the Nephite cultural area has been discussed thoroughly in previous academic articles (Ball, 1993). The conclusion reached is that these terms are referring to a local event that is simply widespread, unless further defined by context.

Chapter 12

Best Fits for Locations and Events

When attempting to recreate an historic hazard event that may have had multiple hazard causes or combinations of causes, an appropriate approach is to apply probabilities for each possible cause. By selecting the most probable cause of each event and applying the premise that the simplest explanation is preferable, one can arrive at what is called a "best fit" cause for each event. A best fit analysis and determination does not mean that there are no other explanations, just that the best fit is the most probable. For example, one could argue that an asteroid strike or an alien attack could account for the description of events in 3rd Nephi, but most reasonable persons would be dismissive of these causes because they have an extremely low probability. In the case of the 3rd Nephi events, there are some best fit probability criteria that will be applied where applicable to arrive at a best fit determination for each of the geographical areas and cities to determine the causes of destruction:

1. Any cause must be consistent with all actual accounts given by those who witnessed the event (or was reported to them). In this case, prophetic visions and divine declarations are considered to be part of this classification.
2. A major earthquake, a major volcanic eruption, and a major hurricane are considered to be equally probable, as all these events are considered rare with typical reoccurrence on the order of hundreds of years.
3. A severe local storm is more probable than an early hurricane.
4. A volcanic event is the most probable natural event (indeed the only) to generate mists and vapors of darkness.
5. Since it has been scientifically established in prior chapters that a volcano and earthquake are needed to account for the witnessed events then:
    a) One fault system of earthquakes is more probable than two fault systems of earthquakes.
    b) A local storm is more probable than a volcanic eruption.
    c) One volcano erupting is more probable than multiple volcanoes erupting.
    d) The volcano being located on the earthquake fault system is more likely than it being located elsewhere.
    e) Multiple, related simultaneous earthquakes are more probable than multiple simultaneous volcanoes erupting.

It is important to note that the witnesses and individuals involved in the 3rd Nephi destruction were not analyzing, interpreting, and classifying the event and all its different geological causes and results, they were just experiencing a large natural disaster. They would not be differentiating the volcano, the earthquake, the thunder, or the sinking of cities on the basis of geologic source. It would have all been one big event to them and for the most part was described as such. As a result, there is inevitably going to be some ambiguity in ferreting out each distinctive geologic event as well as the distinctive damage associated with each, as they were all happening at the same time and some in the same area. Some of the damage is definitely cumulative so the effect of any one individual hazard may be difficult to quantify.

"All the face of the land" Events

As has been previously discussed, the descriptive term "all the face of the land" or similar language typically is encompassed in a specific area such as the land northward or the land southward. Other times it indicates something widespread over Book of Mormon lands, including both the land northward and southward. Similarly, the descriptive term "whole earth" is also used, implying both the land northward and the land southward. The only phenomena mentioned that clearly imply effects over both the land northward and southward are (1) quakings, (2) mist or vapor of darkness, and (3) thunderings.

There is a bit of interpretation as to whether rending or fracturing of the earth would be considered to encompass both the land northward and the land southward. First Nephi 12:4 indicated that the "earth" "rent the rocks" and that the "plains of the earth" were "broken up." First Nephi 19:11 indicated that there was an "opening of the earth" without specific geographic reference. Helaman 14:21–22 indicates that "the rocks" "upon the face of the earth" "shall be broken up," and that the rocks "shall ever after be found in seams and in cracks, and in broken fragments upon the face of the whole earth, yea, both above the earth and beneath." The witnesses in 3rd Nephi indicated that there was a "more great and terrible destruction in the land northward" where "the whole face of the land was changed" in part by the "great quaking" (3 Nephi 8:12). Third Nephi 8:18 seems to be still talking about the land northward when it indicates that "the rocks were rent in twain" and were "broken up upon the face of the whole earth" and were "found in broken fragments" and "in seams and in cracks, upon all the face of the land." As a preface to the brief description of destruction in the land southward, 3rd Nephi 8:6 talks of the terrible thunder "insomuch that it did shake the whole earth as if it was about to divide asunder" implying perhaps that the earthquake did not actually divide the earth in the land southward.

Thus, the regional earthquake clearly involved both the lands northward and southward, due to the reference to the "whole earth" quaking. Clearly the plains area was broken up. The Veracruz fault segment extends some distance into the land southward in the coastal plains area. Movement along the Veracruz segment of the fault is definitely the best fit for the primary earthquake event. There clearly may have been additional movement along the Polochic/Motagua segment of the regional strike-slip fault system, especially considering the fact that the city of Jerusalem in the southern portion of the land southward experienced damage that may be potentially explained by an earthquake. A secondary movement of lesser intensity along the Polochic/Motagua segment would also appear to be included in the best fit scenario.

The mists or vapors of darkness are described as being widespread. The only realistic explanation for this phenomenon is a volcanic ash/tephra cloud disseminated as a result of a volcanic eruption. Occasionally during the initial moments of earthquakes, dust can be generated from shaken buildings or by brief release of sometimes pungent soil gases, but these have never been observed in modern earthquakes to last more than a few hours, and the same is indicated for pre-modern earthquakes by historic anecdote (Wolff et al., 1849, 344–46). Earthquake dust has not been observed to inhibit ignition. Volcanic ash distribution has been historically documented to inhibit combustion and last for days at a time (Kowallis, 1997, 152–53). As discussed in chapter 5, there were certain natural events that continued for three days, and these descriptions are indicative of an ongoing volcanic eruption.

The 1793 San Martín volcanic eruption is a recent example that shows that with an extensive dispersion of ash most if not all of the Book of Mormon lands could have been subject to the effects of volcanic ash. The description of events in the land northward indicate that the volcano erupted in the land northward, with the best fit candidate being the San Martín volcano, with a secondary best fit being Pico de Orizaba. Popocatépetl cannot be completely ruled out even though it seems to be located too far north to produce an ash cloud that would have dispersion in the land southward. As ash cloud distribution is highly dependent on local winds and meteorology it cannot be completely ruled out. Popocatépetl is also located at such a distance that it may be difficult to satisfy the requirement that the sounds of thunder and tumultuous noises described in the Book of Mormon could be heard in the land southward.

Great thunderings were also referred to and described as “shaking the whole earth.” The best fit for this event is the sounds of subterranean and surface phreatomagmatic explosions, which occurred as part of the volcanic eruption. While most volcanoes can exhibit phreatomagmatic explosions, the San Martín volcano is favorably situated (with extremely high rainfall levels and significant ground and surface water) and known for these types of explosions. Again the best fit for this phenomenon is an eruption of the San Martín volcano.

Finally, it is worth noting that the “storm” mentioned in 3rd Nephi does not have an associated geographical description, so cannot be assumed to cover “all the land.”

Land Northward Events

All of the events described as occurring in the land northward are explained by a volcanic eruption and effects of the San Martín volcano or secondarily by the Pico de Orizaba volcano and by a large earthquake along the Veracruz fault system, with the associated earthquake effects including subsidence, landslides, and debris flows.

Whirlwinds are also associated with destruction in the land northward. There have been reports of occasional isolated tornadoes in the Isthmus of Tehuantepec, but the best fit for the whirlwinds referred to in the Book of Mormon seems to be whirlwinds associated with volcanic eruptions, with a secondary possibility being tornadoes spawned by a hurricane.

Destructive whirlwinds that destroy buildings and take people and livestock are common in volcanic eruptions and have been reported in the 1815 Tambora eruption, the 1883 Krakatoa eruption, the 1766 Mayon eruption, the 1947 Hekla eruption, the 1963 Surtsey eruption, and the 1973 Eldfeld eruption (Kowallis, 1997).

Figures 62 and 63 are examples of volcanic whirlwinds although the ones pictured are not that powerful.

Figure 62. Whirlwinds formed following a pyroclastic flow from the eruption of the Sinabung, Indonesia, volcano on January 24, 2014 (courtesy Photovolcanica, 2014)

Figure 63. Waterspout whirlwinds formed from the eruption of Kilauea, Hawaii, volcano in 2008

As a secondary possibility, tornados are common features of hurricanes after landfall. Hurricanes actually produce conditions amenable to tornado genesis. As hurricanes make landfall, storm forces begin to decay, and wind speeds near the land surface fall off more quickly than wind speeds at higher altitudes due to friction at the ground level. This vertical gradient in wind forces, as well as extreme changes in wind direction that occur throughout such a widespread storm system as a hurricane produce the wind shear necessary for tornado formation.

Tornadoes are favorably formed in the front-right quadrant of a Northern Hemisphere hurricane that has hit land. A hurricane moving south and hitting the Isthmus from the north or northeast would place the front-right quadrant of the hurricane in the land northward, which is consistent with the Book of Mormon placement of whirlwinds.

Land Southward Events

There are no specific effects in addition to the effects already ascribed to “all the face of the land.”

City of Zarahemla

The city of Zarahemla took fire according to 3rd Nephi. The Sorenson Model has identified the city of Zarehemla as the archaeological site Santa Rosa in Chiapas, Mexico. The most likely methods for Zarahemla to take fire and have the kind of accelerated burning required to kill a lot of inhabitants are lightening- or earthquake-induced ignition from existing human sources of fire in conjunction with high winds. A volcanic ignition does not seem likely, as the location is more than 100 km from the Tacaná volcano and more than 170 km from the El Chichón volcano. Since the mist or vapor of darkness in the form of a volcanic ash cloud repressed fire, it can also be reasonably postulated that the burning of Zarahemla probably occurred very early in the disaster, probably within the first three hours.

For an earthquake-assisted ignition, Santa Rosa, based on the intensity equations and intensity calculations in chapter 10, would sit in an earthquake intensity zone of 4 to 5 because it lies within 120 km of the edge of the zone of intensity at level 7 (see figure 64).

Under the Mercalli Intensity scale, a 4 or 5 is described as follows:

> IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
>
> V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

It would appear that a regional earthquake along the Veracruz fault may have been enough to overturn candles or other such elements of fire to start the spread of fire. As has been previously mentioned, there is always the possibility of large sympathetic earthquakes along faults near Zarahemla, but that would not be necessary to explain the damage to Zarahemla.

Figure 64. Santa Rosa/Zarahemla distance in relation to the 7 Mercalli intensity zone of a large earthquake along the Veracruz fault segment

The best fit explanation for the destruction in Zarahemla is ignition caused by either lightening or earthquake induced upset of ignition sources with the presence of high winds from a large local storm.

City of Moroni

Moroni was "caused to be sunk in the depths of the sea" with the inhabitants being drowned. In the context, the term "sink" or "sunk" is assumed to be literal in that the actual elevation of the city changed, especially given Jesus Christ's declaration that it sunk. Since the city of Moroni was on the ocean, a change in elevation is obvious once covered by the sea.

The Sorenson model placed the city of Moroni along the north shore of the Mecoacon Lagoon (aka Mecoaca Lagoon), at approximately latitude/longitude 18° 25' 55" N 93° 09' 28" W. This location can obviously only be approximate as the city itself is sunk either into the lagoon or into the ocean.

There may be concurrent events that could cause a flood of sea water to overcome the city, such as a tsunami or storm surge, and cause the drowning of the inhabitants, but unless these events cause subsidence, an additional or alternate hazard must be considered. Beach erosion can occur in a tsunami or a hurricane storm surge, and would typically not be considered significant enough to wash away an entire city, however these types of events might be extensive enough to wash away a city configured to run along a beachfront (we really don't know what size the city of Moroni was;

Sorenson has pointed out that some 'cities' in this area are really just military outposts). The amount of erosion from a tsunami depends somewhat on the topography of the land, but definitely is related to the force of the wave. Seventy-foot tsunamis in the Kuril Islands off the east coast of Russia, following a magnitude 8.3 earthquake on November 15, 2006, and an 8.1 quake on January 13, 2007, caused a loss of 200 cubic meters of sediment per meter of width because of tsunami-induced erosion (University of Washington, 2009). Putting this in a hypothetical situation, assuming that the tsunami erosion was 2 meters deep, that erosion would extend back from the shore 100 meters. If the city was configured running along the length of the beach than 100 meters of it could have washed away with the remaining elevation being 2 meters lower than it was previously.

However, the location of the city is proposed to be on a barrier island or spit between the lagoon and the ocean, so the erosion behavior in this situation can be much different. As the river that fed the lagoon in the 3rd Nephi time frame no longer is present, plus the fact that coastline morphology is constantly changing, an exact geological configuration of the barrier island of the lagoon as it existed 2000 years ago is not known.

A tsunami would be a possibility either by movement on the Veracruz fault, part of which is under water in the Gulf of Mexico, or by a pyroclastic flow or lahar that entered the Gulf of Mexico adjacent to the San Martín volcano. In addition, a tsunami risk has been identified in the southern Gulf of Mexico from submarine landslides, which an earthquake may also have triggered (Brink et al., 2009).

Figure 65. Barrier Island breach with new inlet created (Valvo et al., 2005)

A storm surge or a tsunami can completely remove barrier beach areas. If a storm surge fully inundates a barrier island or spit, currents flowing across the area can create a breach or inlet. Waves and surge from the 2003 landfall of Hurricane Isabel created a breach in excess of 500 meters (see figure 65) in the Cape Hatteras National Seashore. This event was not considered remarkable and is typical of what happens to other coastal areas. The elevation at Cape Hatteras of the inlet breach area went from 9 meters above sea level to 1–2 meters below sea level, so this type of event would clearly meet the change in elevation criteria for the city of Moroni to be "sunk." In the case of the city of Moroni, the breach effect would have been compounded because water washing into the lagoon from a tsunami or storm surge would also need to exit back into the ocean causing additional erosion of material as massive amounts of water flowed back through the breach.

Moroni itself does not sit within the anticipated area of direct earthquake subsidence but is located in an area of soils susceptible to earthquake amplification of 1.6 points on the Mercalli intensity scale. Being 43 kilometers from the intensity level 8 area (see figure 66) would put it in the intensity level 7 area and by addition of the amplification factor would be 8.6. Because of the susceptible soils, liquefaction could also be a contributing factor to the subsidence. Liquefaction can account for a drop in elevation as it can turn soils essentially into a flowable fluid, which can cause large portions of coastal beach to collapse into the ocean.

Figure 66. Distance from Moroni to level 8 intensity area

The disappearance of a city into the ocean caused by a large earthquake and subsequent liquefaction is not farfetched. In 1692 the pirate port city of Port Royal in Jamaica was hit by a large earthquake. The city was built on a large spit of sand, the sand being saturated with water close to sea level. On June 7, 1692, the devastating earthquake hit the city causing liquefaction of the sand, which caused it to flow out into Kingston Harbor. Most of its northern section fell into the sea (and with it many of the town's houses and other buildings). In addition, the island lost many of its forts. Fort Charles survived, but Forts James and Carlisle sank into the sea. Fort Rupert became a large region of water, and great damage was done to an area known as Morgan's Line. A map showing the extent the Port Royal sank into the sea has been created by a contributor to Wikipedia (see figure 67) based on the historical locations and the currently existing submarine surviving portion of Port Royal (which still exists under 12 meters of water and is a popular diving location).

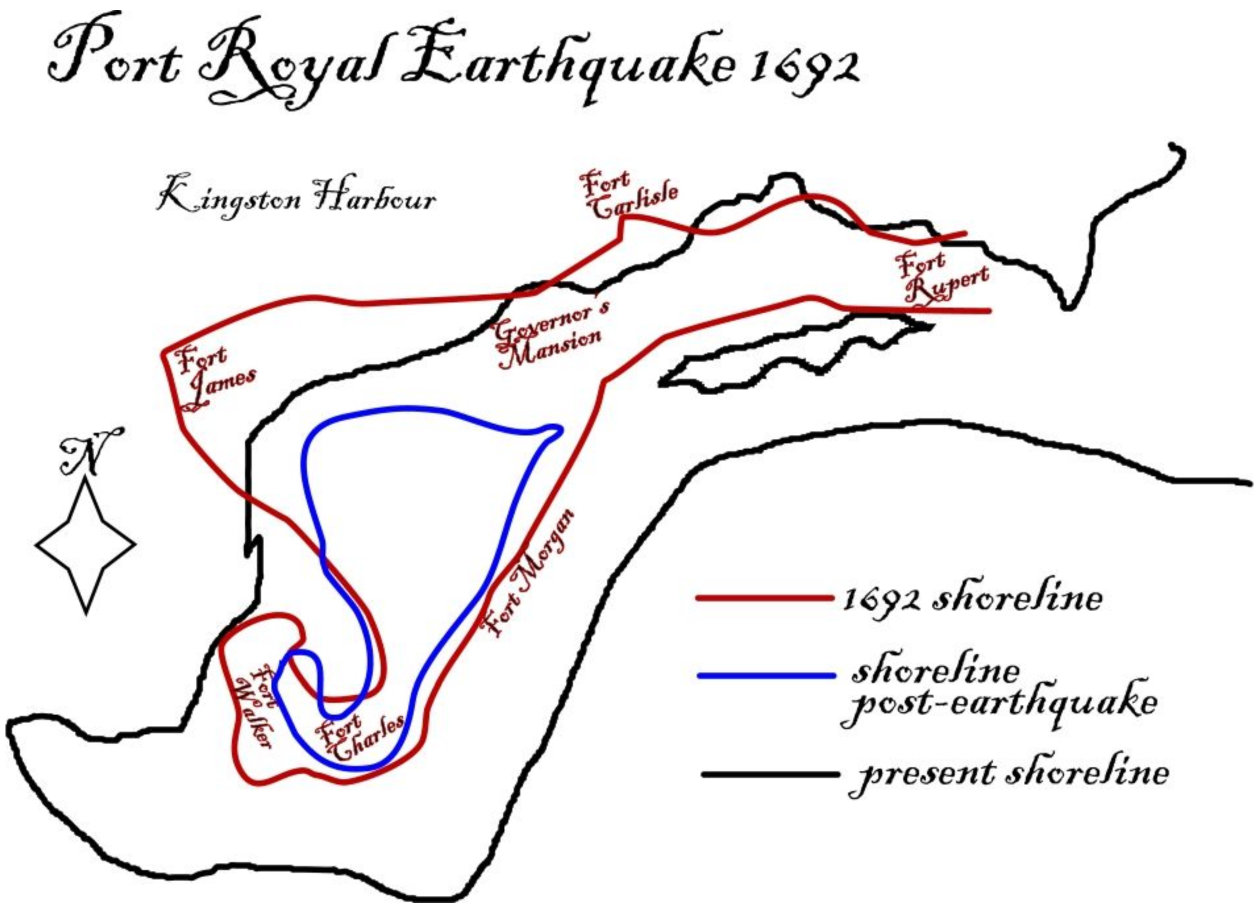


Figure 67. Portions of the city of Port Royal, Jamaica, that sank into the ocean

An examination of recent earthquake data also shows that there are some shallow and intermediate depth earthquakes within 30 kilometers of the proposed city of Moroni, so it is possible there may be an unmapped fault that might also have triggered subsidence in the area.

A best fit explanation for the destruction of the city of Moroni would be a combination of earthquake damage and liquefaction and the impact of one or multiple tsunamis triggered by submarine earthquake movement of the Veracruz fault, a Gulf of Mexico submarine landslide, or volcanic deposition impact into the Gulf from the San Martín volcano. Secondary possibilities would be the impact of a hurricane landfall and a local earthquake on a currently unidentified fault trace. The location specified for the city of Moroni under the Sorenson model is a reasonable fit for the known geology and hydrology.

City of Moronihah

The Sorenson model and Book of Mormon text does not geographically locate the city of Moronihah except that it is in the land southward. The destruction of the city was characterized that "the earth was carried up" upon the city, and that in "the place of the city there became a great mountain." There is no mention of the city sinking, so any hazard scenario would have to assume that the city was buried close to its pre-disaster elevation.

Sorenson opines that the city should be located in the area of the east sea because that is where Moronihah operated as a military leader. This area is a bit problematic in relation to the description of the 3rd Nephi destruction as the land is relatively flat, thus making the "earth carried up" and "became a great mountain" description inconsistent with the hazard types possible in a flat area.

Significant deposition of sediments from a flooded river or a natural dam break might be a possibility if the flood deposition occurred over a significant time period, as dam break overflow deposits can exceed 10 meters in depth, however the deeper deposits generally fill areas of lower elevation and would thus not be considered "carried up." Generally flood-caused deposition is determined by the duration of the extreme flow and the steepness of the slope of the channel, which steepness would not be present in the flat east sea area (Costa, 1988). In addition, while river flooding, tsunami, and hurricane storm surge can "carry up" silt and rock deposits, they have not been observed to create deposits that most would describe as a "great mountain" but are typically in the form of river bars and widespread floodplain sediment deposits, with maximum deposits not exceeding a few meters in elevation.

The area along the Isthmus east sea does fall within a known petroleum and gas basin, so it seems the only possibility that might meet the requirements in the flat terrain is a mud volcano. A mud volcano is caused by areas of underground natural gas overpressure that undergo a pressure explosion, releasing mud to the surface, sometime in large amounts. The mud produced by mud volcanoes is most typically formed as hot water, which has been heated deep below the earth's surface and begins to mix and blend with various subterranean mineral deposits, thus creating a mud slurry. This material is then forced upwards through a geological fault or fissure due to certain local underground pressure imbalances.

Given time, mud volcanoes can become quite large. The largest mud volcano structure, Indonesia's Lusi, which started erupting in 2006, is 10 kilometers in diameter and reaches 700 meters in height.

Significantly sized mud volcanoes can occur within the time frame of the 3rd Nephi disaster (less than three days, probably quicker to account for the high mortality rate). On September 24, 2013, a major strike-slip earthquake rattled western Pakistan, killing at least 350 people and leaving more than 100,000 homeless. The 7.7 magnitude quake struck the Baluchistan province of northwestern Pakistan. Amidst the destruction, a new island was created offshore in the Paddi Zirr (West Bay) near Gwadar, Pakistan (see figure 68). This mud volcano was approximately 100 meters high from its base of the sea floor with a base in excess of 600 meters wide.

Submarine mud volcanoes are a common occurrence in the northern Gulf of Mexico, but none have been reported near the Isthmus. Since a mud volcano adjacent to the east sea would have to occur in conjunction with a large earthquake, it is possible that an historical mud volcano could have occurred in this area. In a sub-tropical climate with heavy rainfall, a mud volcano deposit would not last very long and would be eroded away, so there would be little possibility of locating any remaining mud volcano deposits.

Since there is no geographical placement of the city of Moronihah within the Sorenson model it does not absolutely require that the city of Moronihah be located along the east sea. The hazard description given in the Book of Mormon text better fits a mass movement landslide in a valley setting, specifically a mass movement that pushes up a large ‘mountain’ of material on the opposite side of the valley or ridge. There are two scenarios where this might occur, one would be a large debris avalanche from a volcanic eruption that runs up and and even over areas of topographic relief such as a ridge, an event that occurred during the 1980 eruption of Mount St. Helens (Daniels, 1982, 154); the other would be a large landslide that can occur in valleys with a particular type of geology, often triggered by an earthquake.

Figure 68. Pakistani Mud Volcano formed by 2013 earthquake (NASA, 2014)

Since Moronihah is located in the land southward, there are a few volcanoes (see chapter 3) that were active during the 3rd Nephi period that might be attributed to the destruction of the City of Moronihah, however, there is no direct indication of a volcanic eruption in the land southward in the 3rd Nephi narrative. Rather than a volcanic debris avalanche or pyroclastic flow, one Book of Mormon commentator has suggested that the great mountain might have been a monogenetic volcano (Gardner, 2007, 304), which is a volcano that erupts once and forms from the ground up, with the classic example of the volcano Parícutin that came out of a Mexican farm field (see figure 25). However, all monogenetic volcanoes in the land southward were formed and inactive long before Book of Mormon times.

While there are multiple possibilities, a tentative best fit for the city of Moronihah, and the most probable scenario, is a large landslide that creates a mountain against or because of the opposite valley wall. On November 4, 2007, along the Grijalva River in the state of Chiapas, Mexico, occurred one of the largest landslides ever known. This landslide, known as Juan del Grijalva landslide, destroyed the town of the same name, creating a water and mud wave 50 m high that destroyed the Juan del Grijalva town, killing 20 people and moving 55 million cubic meters of rock and debris down slope to completely block the Grijalva River. According to records from the last century, the Juan del Grijalva landslide represents one of the largest mass movements of earth recorded.

Figure 69. Great Mountain left by the 2007 Juan del Grijalva landslide into the Grijalva River (Reuters, 2007)

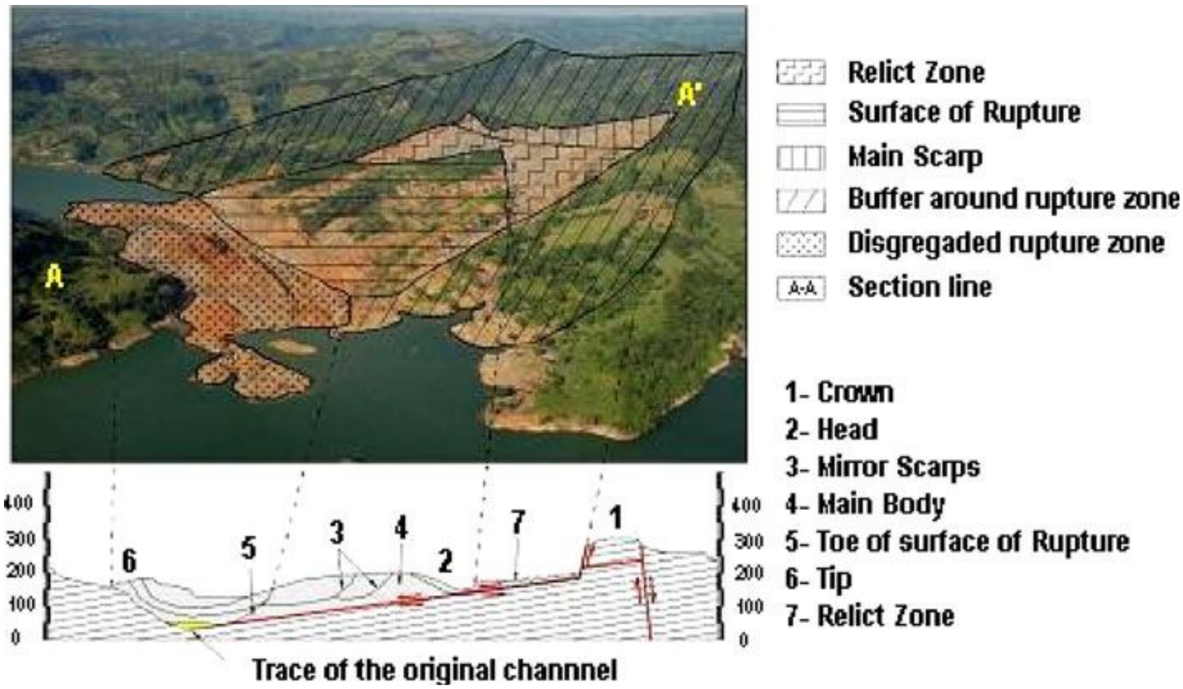


Figure 70. Diagram and cross section of the 2007 Grijalva River landslide showing the burial of the original channel (Serrano et al., 2011)

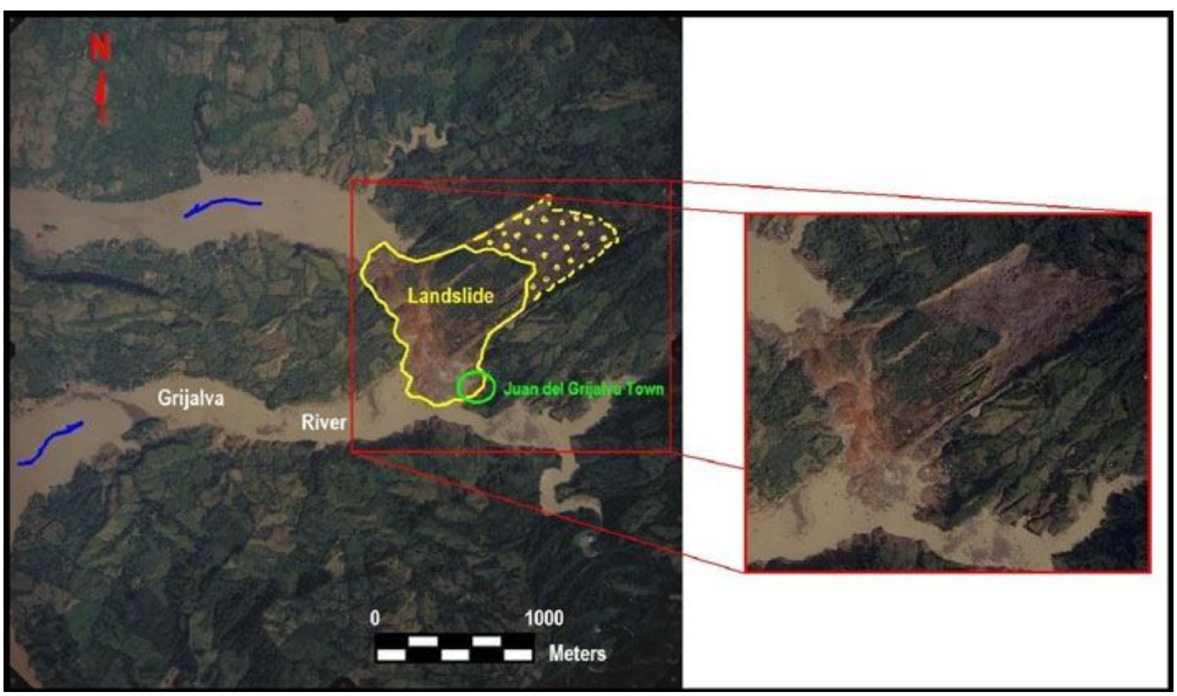


Figure 71. Aerial view of 2007 Grijalva River landslide showing location of the Juan del Grijalva Town (Serrano et al., 2011)

The landslide went through the river, burying the river and whatever was on the riverbank on either side of the river, leaving what could clearly be described as a “great mountain” (see figure 69). The original bed of the river was buried in 100 plus meters of material (see figure 70). The town of Juan del Grijalva was actually along the margin of the landslide but still was destroyed and lives were lost (see figure 71).

In most areas where these types of large landslides have occurred, they are reoccurrences of prior landslides along the same plane of slip. Essentially, once these landslides occur, the river backs up against the landslide material forming a lake until it overtops the landslide material. Once it overtops, it creates a new channel, generally following the alignment of the previous channel. Over time, the toe of the landslide is eroded away. Once the landslide toe material has eroded away, the resistance to slip for the rest of the landslide is removed, allowing for another reoccurrence of the landslide.

It is likely that the Juan del Grijalva landslide is one of these situations, and might be a good candidate location for the landslide that destroyed Moronihah. The landslide area is within the 3rd Nephi regional earthquake Mercalli Intensity level 8 zone, and as previously noted, this is the zone where large landslides are expected to be triggered (see figure 72). While not in the exact area opined by Sorenson as the location of Moronihah, it (or a different landslide further down the Grijalva River valley) would be closer than a volcanic eruption landslide might be.

Figure 72. Location of the 2007 Grijalva River landslide in relation to hypothetical 3rd Nephi earthquake Mercalli Intensity level 8 zone

The best fit for the destruction of Moronihah is a large landslide in a river valley within the intensity level 8 zone of the regional earthquake, with secondary possibilities being a mud volcano or volcanic debris avalanche.

City of Jerusalem

The city of Jerusalem has been identified in the Sorenson model as being on the south shoreline of Lake Atitlán (figure 73), with the identification of the recently discovered submerged city of Samabaj being a prime candidate. There are actually a few potential interpretations of the Book of Mormon text with regards to the demise of the city of Jerusalem. The first is that the waters were caused to "come up in the stead thereof" as limiting the method of demise to the description given in 3rd Nephi 9:7, which is the most common interpretation and the one that Sorenson prefers.

Figure 73. View of the south shoreline of Lake Atitlán, Guatemala (courtesy of wikipediacommons.org)

One reason to believe that there may be additional geologic events going on here is that 4th Nephi 1:9 later states that "there were many cities which had been sunk and waters came up in the stead thereof," indicating that the city of Jerusalem may have in fact physically sunk in addition to the waters coming up, if it was indeed one of the cities referred to in 4th Nephi.

In another interpretation, one which would add the additional events of sinking and burial to the demise of the city of Jerusalem, it has been suggested (Ainsworth, undated) that verses 6 and 7 need to be read together, since the punctuation was not part of the original Book of Mormon translation, and in order to square with the language of 4th Nephi.

The text of the Book of Mormon can be interpreted to say that Jerusalem was sunk and buried with water coming up in the stead thereof when reading verses 6 and 7 in 3rd Nephi 9. The current verses are as follows:

> 6. And behold, the city of Gilgal have I caused to be sunk, and the inhabitants thereof to be buried up in the depths of the earth;
>
> 7. Yea, and the city of Onihah and the inhabitants thereof, and the city of Mocum and the inhabitants thereof, and the city of Jerusalem and the inhabitants thereof; and waters have I caused to come up in the stead thereof, to hide their wickedness and abominations from before my face, that the blood of the prophets and the saints shall not come up any more unto me against them.

Ainsworth argues:

> These verses are divided in a very unusual way. Verse 6 is essentially a fragment of a sentence, ending in a semi-colon (;), not a period. Verse 7 then continues the sentence of verse 6, with *"Yea, and the city of Onihah and the inhabitants thereof…"*
>
> …[T]he use of the term *"Yea, and …"* in the Book of Mormon and it appears 280 times. In 123 cases, this term appears in the middle of a sentence, following the semi-colon (;) of the previous sentence—continuing with the same trend of thought, in the same paragraph.
>
> In 83 cases the term *"Yea, and …"* appears at the beginning of a paragraph, but in only five of these cases, does the previous paragraph end with a semi-colon (;), as in 3 Nephi 9:6-7. Put another way, in addition to 3 Nephi 9:6–7, there are only four other places where one verse ends with a semi-colon, to be followed by the next verse beginning with *"Yea, and…"*
>
> In these other four cases, the second verse, the one beginning with "*Yea, and…*" is a continuation of the thought of the preceding verse—which ends in a semi-colon. (See Mosiah 18:9, Alma 9:22, Alma 13:22, and Helaman 8:9.)
>
> … [I]n my opinion 3 Nephi 9:6-7 should be read as one paragraph, not two, with verse 7 simply being a continuation of what is being described in verse 6.
>
> Here are the two verses as I think they should appear, providing more clarity to what is being described in these two verses:
>
> 3 Nephi 9:6–7 (combined). And behold, the city of Gilgal have I caused to be sunk, and the inhabitants thereof to be buried up in the depths of the earth; yea, and the city of Onihah and the inhabitants thereof, and the city of Mocum and the inhabitants thereof, and the city of Jerusalem and the inhabitants therefore; and waters have I caused to come in the stead thereof, to hide their wickedness and abominations from before my face, that the blood of the prophets and the saints shall not come up any more unto me against them.
>
> Reading the two paragraphs this way changes the meaning of the verses dramatically. Now the event being described is one of four cities sinking into the earth, and then waters filling up the area where these cities once stood.

> Reading the verses this way allows the last comment of verse seven, (… to hide their wickedness …) to apply to all four cities, rather than just three, which makes more sense to me.

Notably, although not mentioned by Ainsworth, there is no mention of the inhabitants "drowning" as was used to describe what happened to the inhabitants of the city of Moroni. The reading of the verses to include sinking and burial as well as inundation would be consistent when considering 4th Nephi 1:9 with regards to sinking, however it would be inconsistent in that 4th Nephi 1:9 does not include burial.

Because of the variability in possible textual interpretations, it will be necessary to look at the best fit analysis using three scenarios with regards to the city of Jerusalem in light of its location in the Sorenson model and others as being on the south shore of Lake Atitlán:

1. The city did not change elevation, but Lake Atitlán raised a sufficient level to cover the city
2. The city sunk, with the potential that the level of Lake Atitlán was also simultaneously raised
3. The city was sunk, buried, and inundated by water in the vicinity of Lake Atitlán

Since the exact elevation of the city and the lake in the first century AD is not exactly known, it will be necessary to make the assumption that the city was adjacent to the shore of the lake on relatively flat land. For purposes of this analysis, the assumption is that a 10 meter rise in the elevation of the lake (or drop in the elevation of the city) would be sufficient to meet the description that the waters have come up "in the stead thereof."

Scenario 1: Rise in the elevation of Lake Atitlán without subsidence of the city

The only identifiable methods for raising the level of Lake Atitlán are:

- Change in the hydrological regime by decreasing outflow and/or increasing inflow to the lake
- Introduction of material into the lake sufficient to raise the elevation of the lake or a change in the lake bottom geometry

Scenario 2: Rise in the elevation of Lake Atitlán and/or subsidence of the city

In this scenario the identifiable methods are:

- Change in the hydrological regime by decreasing outflow and/or increasing inflow to the lake
- Introduction of material into the lake sufficient to raise the elevation of the Lake or a change in the lake bottom geometry
- Subsidence of a portion of the lake

Scenario 3: Rise in the elevation of Lake Atitlán and/or subsidence of the city with burial of the city

In this scenario the identifiable methods are:

- Change in the hydrological regime by decreasing outflow and/or increasing inflow to the lake
- Introduction of material into the lake sufficient to raise the elevation of the lake or a change in the lake bottom geometry
- Subsidence of a portion of the lake

- Burial by volcanic deposition or landslide

Hydrology of Lake Atitlán

Lake Atitlán is a lake in the Guatemala highlands. It is scientifically classified as endorheic, which means there is no surface outfall. Water leaves the lake through a presumed system of subterranean fractures and/or permeable deposits. Thus, while the inflow to the lake is quite variable depending on weather conditions and especially the occasional hurricane that crosses the region, the outflow remains constant. In consequence, the lake level is quite variable; during extended dry periods the lake level falls and during periods of higher than average rainfall the lake level can rise. The lake is also fed by two rivers, Rio Quiscab and Rio Panajachel.

Atitlán is recognized to be the deepest lake in Central America with maximum depth about 340 m (1,120 ft). The current surface area of the lake is approximately 123 km^2, with around 24 cubic km of water. The lake is shaped by deep escarpments that surround it and by three volcanoes on its southern flank. The lake basin is volcanic in origin, filling an enormous caldera formed in an eruption 84,000 years ago. A caldera is a large volcanic crater formed by an explosion and collapse of the central part of a volcano.

While the outflow remains constant under normal conditions, because the outflow is subterranean, the outflow can be affected by geologic events, specifically earthquakes. In 1976 an earthquake caused a drop of the lake level by 5 meters in a month (Medrano, 2011).

The question related to hydrology involving 3rd Nephi events is whether the hydrology could generate a rise in lake levels enough to cover a city in less than 3 days. In order to perform these types of analysis, it is necessary to determine the volume of water needed to raise the lake sufficient to cover a level city presumably located at or near the water line. It is assumed that 3 meters of water would be sufficient to cover a level city located on the water line. We know that the water line in Book of Mormon times was at least 17 meters below the current average water line based on the known depth of the submerged city of Samabaj (Medrano, 2011). The current surface area of 123 km^2 would not exist at that time; using bathymetric diagrams of the lake, it is estimated that the surface area in those times would be in the neighborhood of 110 km^2. Using these figures, it would require .33 km^3 of water to be added to the lake in a 3-day period of time in order to inundate a city.

Severe historic hurricanes have generated up to 1.9 meters of precipitation during the hurricane event. The catchment area of the Lake Atitlán is 548 km^2 so assuming that the base flow of the river and outfall seepage are in steady state, and that all of the rainfall made it to the lake in a 3-day hurricane period (which is not realistically scientifically going to happen, even in a situation where soils were previously supersaturated, or in the alternative, completely impermeable soils) than the lake could theoretically rise 10 meters in height, more than exceeding the 3 meters needed for submersion of a city.

However, in order to determine what the actual increase in level might be, additional hydrological studies would need to be completed, but it remains a possibility.

Geology Related to Submersion of the City of Jerusalem

An extensive geologic study of the lake was conducted in 1979 (Newhall et al., 1987). The study identified and reached these conclusions (among others):

- There is a probable landslide deposit at the foot of a large landslide scarp that was overlain by 10-15 m of sediment, and thus occurred at least 1,000 and probably several thousand years ago.
- Lava flows from the adjacent Tolimán volcano and its parasitic vent, Cerro de Oro, have occurred within a few (1-2?) thousand years.
- Seismic reflection profiles showed at least 175 m of flat-lying, undisturbed sediments, the result of at least 17,500 years and probably 35,000 year or more of sedimentation. No source vents for either the caldera-forming or subsequent eruptions were identified within these profiles. No resurgent doming or regional faulting is apparent within the same 175 m of sediments in the reflection profiles.

No regional faulting was detected within the sediments at the bottom of the lake during the 1979 study, however gas present in lake sediments made the seismic readings incomplete and inconclusive in determining faulting in the bedrock under the sediments. The study did not evaluate adjacent surface faults. There are local caldera related faults around the lake that may have had past activity, but additional mapping and research will be needed to determine time and amount of movement, if any (Newhall, 1987). Additional research would need to be completed as to the amount of landslide material and/or lava that may have entered the lake during those events to determine what the resulting rise in lake levels might be.

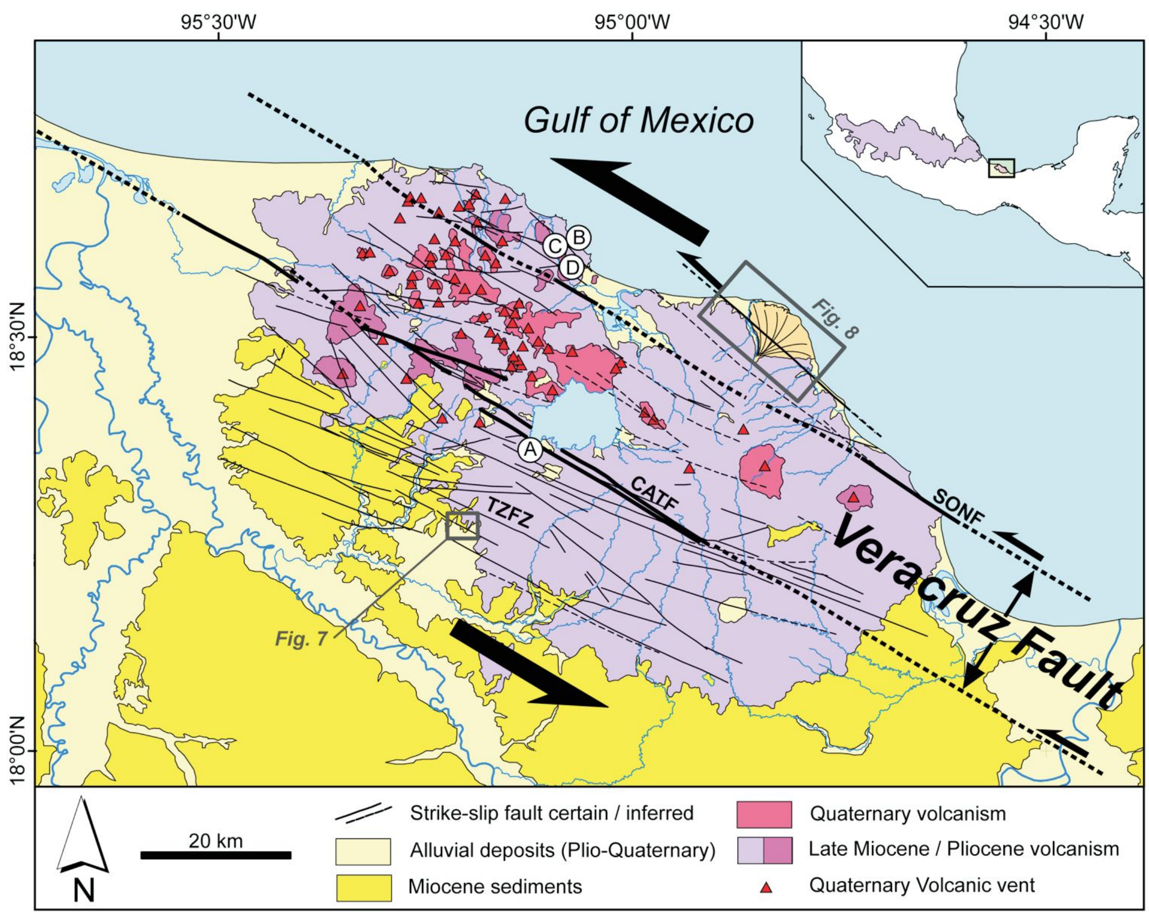
At this point, there is really no scenario that can be ruled out with regards to the city of Jerusalem as there is simply more data to be found and research that needs to be done. Rising water with or without subsidence and with or without burial are all possible. Sorenson's preference for Samabaj as the city of Jerusalem would rule out burial, since the only apparent burial on the site is post submersion lake sediments. Samabaj apparently has some topographic relief so might involve a higher rise in lake levels to be inundated. Since it is not known whether the volcanic activity or the landslide event happened during the correct time frame, any best fit scenario determination at this point would be premature.

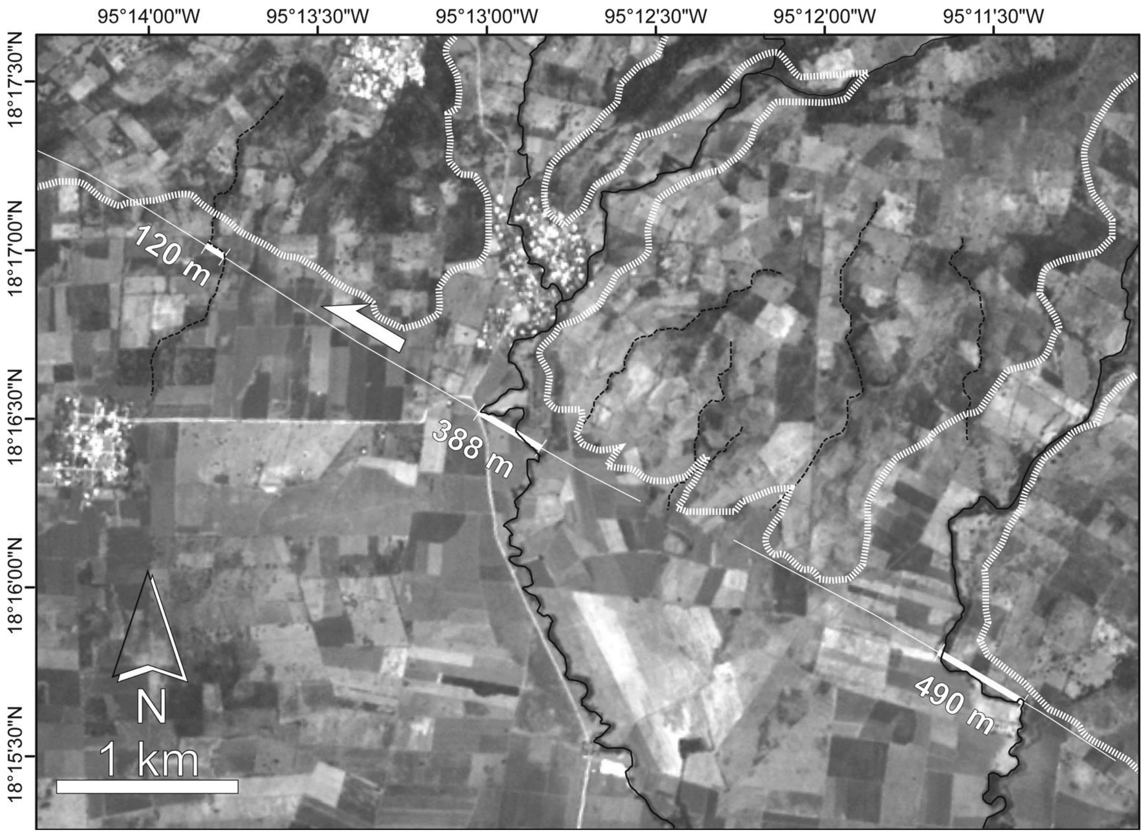
Cities of Onihah and Mocum

The discussion involving the cities of Onihah and Mocum is identical to that of the city of Jerusalem except that these two cities do not have any geographical placement in the Sorenson model, although they may also be located somewhere on the shoreline of Lake Atitlán.

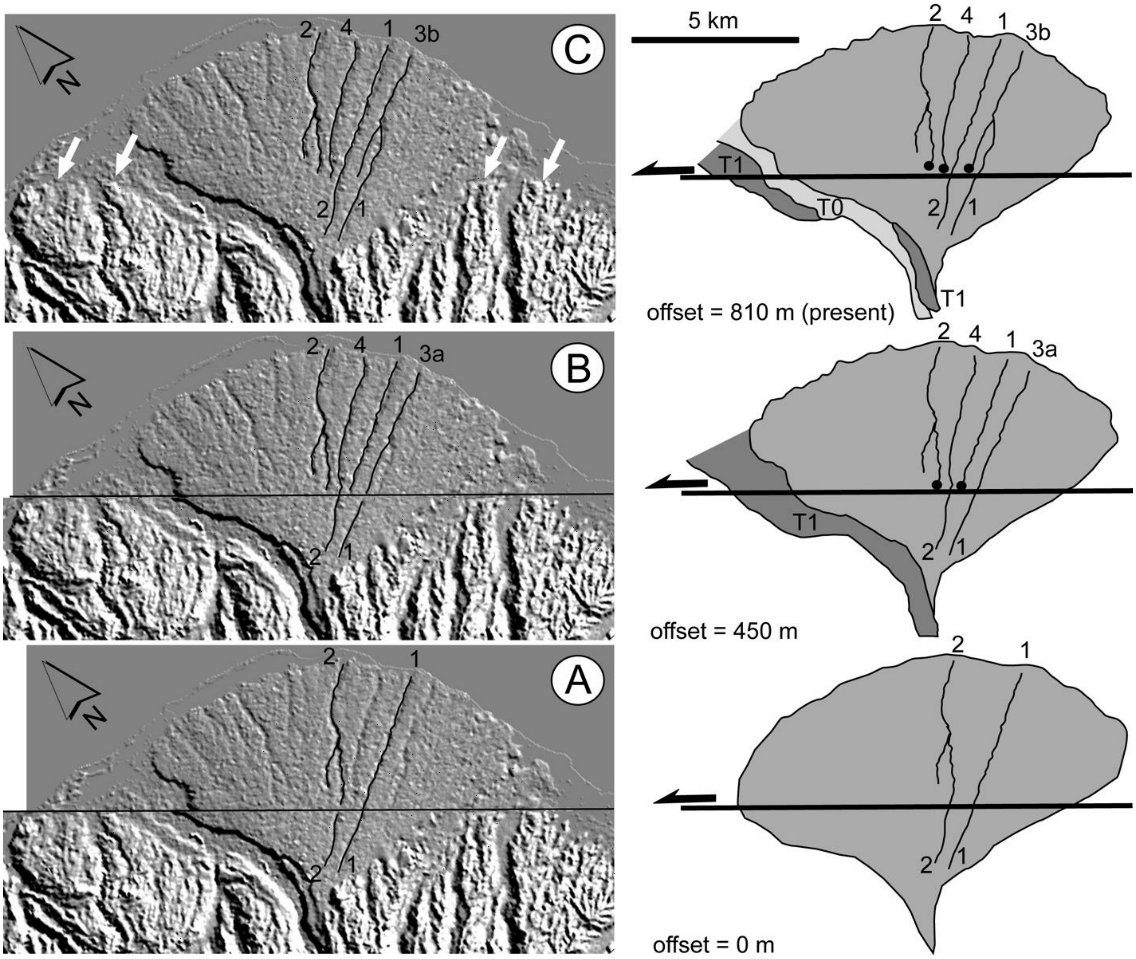
Initially, the Book of Mormon text seems to exclude by silence the possibility of these cities being located adjacent to and being inundated by the sea. The city of Moroni is specifically described as being sunk into the depths of the sea. No such language is found describing the cities of Jerusalem, Onihah, and Mocum. These cities are therefore considered to be located along a water body such as a lake, lagoon, or river, or in an area of high groundwater.

If there is no subsidence involved, the cities would obviously be located on a water body that might somehow have the water levels elevated a significant amount. For a lake, the water levels would rise with the introduction of landslide or volcanic deposits to the lake to raise its elevation. If the cities were along a river, blockage of the river by landslide (similar to the landslide description for the city of Moronihah), or the beheading of a river by later strike-slip fault movement could account for the inundation. Beheading of a river happens when the fault moves the channel of the river sideways, generally impounding the water, sometimes creating a permanent impoundment. Examples of this type of event have been documented in the area of the Tuxtla Mountains, and have probably occurred in other locations. The discussion and examples of this are included here are taken directly from Andreani et al., 2008, as a combined figure 74 (the three following images).





This is a satellite image of an area located in the southwestern part of the Los Tuxtlas volcanic field (the location designated by “Fig. 7” in the preceding image). A discrete fault trace is evidenced here by systematic left-lateral river offsets and by the sharp termination of the volcanic plateau (white dashed lines).



This is a digital elevation model of an alluvial fan in the northeastern part of the Los Tuxtlas volcanic field (the location designated as "Fig. 8" in the first image) and its possible evolution. A fault (marked by white arrows) sharply cut the volcanic deposits and an alluvial fan. Left-lateral movement along the fault is evidenced by the disposition of beheaded channels. The maximum offset obtained by restoring the channels is 810 m. A – The possible initial development stage of the alluvial fan with two main incisions. The fan was probably directly fed by the river. B – The fan is dissected on its left side by the river (deposition of the T1 alluvial terrace). The fault displacement cuts the streams on alluvial fan. The 1 and 2 beheaded lower streams are replaced by new ones (3a and 4). C – The present situation with an entrenchment of the river (T0 alluvial terrace) and a new stream displacement. The lower stream 1 is captured by the upper stream 2.

Figure 74. Combined figures and discussion of beheaded streams from lateral strike-slip movement (Andreani et al., 2008)

Inundation by a river beheading process would be expected only in the area of fracture and rupture identified by figure 61. If a river is blocked by landslide or a lake elevation is raised by landslide causing an adjacent city to be inundated, then the expected area where that might occur is identified in figure 59. If there is a river that is blocked by volcanic deposition or a lake elevation that is raised by volcanic deposition in the lake causing an adjacent city to be inundated, then the expected area where that might occur is identified in figure 76.

If subsidence causes inundation of a city that is adjacent to a lake or river, or is located in an area of high groundwater, then the expected area where that might occur is identified in figure 61. As some interpretation of the text would indicate burial, this would indicate burial by either a landslide or by volcanic deposition, indicating that this would occur in areas shown in figure 59 or figure 76 respectively.

The above listed interpretations would all be the best fit locations for Mocum and Onihah given the potentially different parameters dictated by the varying textual interpretations. A secondary best fit interpretation could also place these cities along the shoreline of Lake Atitlán if in fact the entire Lake was raised in elevation as discussed in the situation of the city of Jerusalem. If Jerusalem, Mocum, and Onihah are not the cities referred to in 4th Nephi, then the best fit analysis described here would also apply to those unnamed cities that were actually sunk.

Cities of Gadiandi, Gadiomnah, Jacob, and Gimgimno

The cities of Gadiandi, Gadiomnah, Jacob, and Gimgimno are described as being “sunk and made hills and valleys in the places thereof” with their inhabitants being “buried up in the depths of the earth.” The subsidence element places them within the area shown in figure 76. The “hills and valleys” description is quite informative as it is a perfect description of the uniquely hummocky deposits of many volcanic debris avalanches and some volcanic pyroclastic flows (see figure 75). These were not really recognized as a unique identifying landform of volcanic deposits until after the 1980 Mount Saint Helens eruption.

Figure 75. Hills and valleys (hummocks) formed by 1980 Mount St. Helens eruption debris avalanche and pyroclastic flow (USGS, 1999)

Hummocks and mounds have been identified as features in some other non-volcanic large earth landslides, but are most common in volcanic landslides and pyroclastic flows. The cities mentioned here were probably somewhat near each other, as volcanic landslides and pyroclastic flows are very directional. A typical volcanic eruption with pyroclastic flows will have one direction of eruption, sometimes two. The tectonic setting of the volcano may influence the direction of collapse and in some cases faulting may trigger collapse.

For purposes of locating the cities of Gadiandi, Gadiomnah, Jacob, and Gimgimno in reference to the "hills and valleys" method of burial, the best fit is clearly within the range of a pyroclastic flow or volcanic debris avalanche of a volcano. The best fit volcano is San Martín, because Pico de Orizaba is not within the best fit area of subsidence. As mentioned in chapter 3, the report from the 1793 eruption of San Martín indicated that the fallout was from at least 3 yards up to 6 yards thick located in a circle around the volcano with a diameter of 11.1 kilometers. Assuming that one could bury a city with a minimum of approximately 2 to 2.5 meters of material, and accounting for a potentially larger volcanic eruption than the 1793 eruption, a much greater distance than 5 km from the volcano cone would be possible for city burial.

Based on archeological excavations at Tres Zapotes (Jaime-Riverón and Pool, 2009, and Santley, 2007) and Lake Catemaco (Santley et al., 2000) that identified volcanic deposits within the time frame of 3rd Nephi, a reasonable extent of these deposits would be 26 km from the San Martín cone.

Without more detailed mapping of volcanic deposits, it is necessary to consider that the eruption could have gone in any direction when assigning an area where Gadiandi, Gadiomnah, Jacob, and Gimgimno might have been located. In addition, the inactive volcano south of San Martín called San Martín Pajapan volcano has a crater that opens to the east with debris avalanche deposits extending 20 km to the Gulf of Mexico and the Santa Martha Volcanic Complex adjacent to San Martín Pajapan has two craters opening to the south with debris avalanche deposits (Capra et al., 2002), so lacking any more exact mapping and dating of the debris avalanche deposits these areas must be considered as a possible areas of "hill and valley" burial as these structures also sit in the earthquake zone of subsidence. Therefore, the area identified in figure 76 would be a reasonable area where one might expect to find the cities Gadiandi, Gadiomnah, Jacob, and Gimgimno, with the likelihood that some or all of them are located near each other.

Figure 76. Zone of "hills and valleys" deposition either from volcanic eruption deposits (within 26 km of cone) or debris landslides

City of Gilgal

The city of Gilgal was sunk and covered with earth. Subsidence places the city in a best fit scenario within the level 8 Veracruz fault area identified in figure 61. In order to be covered with earth, it would have to either be in the "hills and valleys" area shown on figure 76 (even though the final cover is not described as a hill and valley, it is possible that not all of the material deposited would have formed hills and valleys) or in an area where significant adjacent slopes exist subject to landslides, typically in a valley. Given the fact that there is a reference to the valley of Gilgal in the book of Ether, the valley scenario is considered the best fit for this city. The best fit for the city of Gilgal is the area identified in chapter 10 (figure 61) within the Mercalli level 8 earthquake zone where most major earthquake-triggered landslides would be expected to occur.

Cities of Jacob-Ugath, Laman, Josh, Gad, Kishcumen

The descriptions given of the destruction of Jacob-Ugath, Laman, Josh, Gad, and Kishcumen are that they were "caused to be burned with fire"; and Jesus Christ "did cause them [the inhabitants] to be burned" and "did send down fire and destroy them." The most obvious explanation for this method of destruction is ignition of the cities by volcanic fallout. No mention is made of these cities sinking, so they may or may not have been within the zone of potential earthquake subsidence. Also this is obviously a different description than Zarahemla, which merely did "take fire." It seems pretty clear that the city and the individuals in the cities and the cities themselves were directly burned by the fire that came from the sky, not by a secondary conflagration caused by a lightning strike or an earthquake triggered event.

There are no real studies that model the maximum distance that can be covered by incendiary material from a volcanic eruption. Clearly the closer to the volcano, the higher chance there is of hotter fallout occurring. Meteorological patterns can also be influential as the cooling of volcanic material is a function of the time elapsed since ejection from the volcano. The best information for a maximum area of incendiary material probably comes from the eruption of Krakatoa where ash fallout 70–80 km from the volcano was still hot enough to burn holes in clothing and vegetation (Bryant, 2005, 233). Using the 70 km distance, the San Martín volcano area identified in figure 77 is the best fit probable area where the cities Jacob-Ugath, Laman, Josh, Gad, and Kishcumen were located, with secondary possibilities being a 70 km area around Pico de Orizaba or Popocatépetl (not shown in figure 77).

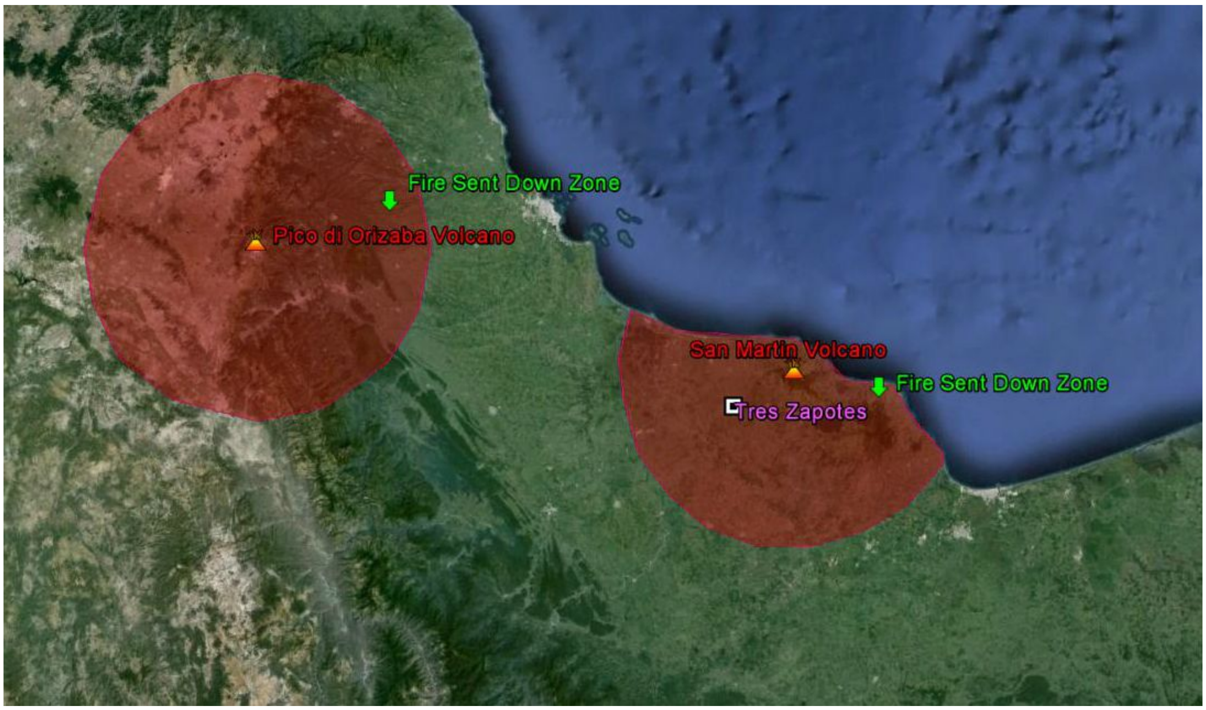


Figure 77. Zone of raining of fire for the Pico de Orizaba or San Martín volcanoes (within 70 km of the cone)

City of Bountiful

The temple in the land of Bountiful is not noteworthy because of the description of its destruction, but is noteworthy because it was apparently not destroyed as is recounted in 3rd Nephi 11:1. It was also situated in a geographic position such that the people were observing "the great and marvelous change that had taken place." The scriptures do not say what the level of damage may have been at the temple or in the land of Bountiful, but the location clearly was positioned to support a multitude of 2500 persons (3rd Nephi 17:25) who were at or near the temple, and after Jesus appeared these men, women, and children were told to return to their homes (3rd Nephi 17:3), which they later did (3rd Nephi 19:1). The locale also contained or was immediately adjacent to a much larger population than 2500 persons because overnight, just by word of mouth, an "exceedingly great number" of persons were on hand the next day (3rd Nephi 19:3). The temple was also adjacent to some type of body of water (3rd Nephi 19:10).

Houses were apparently still standing and habitable, and a large number of persons survived whatever damage had occurred (if any). The scripture does not refer to the city of Bountiful, but refers to the temple that was in the land of Bountiful. It is clear from the number of people at the temple with homes nearby that the temple was located in or immediately adjacent to a city. Although the scripture does not explicitly identify the “city” of Bountiful, it can be inferred that the temple was located at the city of Bountiful. There is some indication that on at least on one occasion, the term “land of Bountiful” and the term “city of Bountiful” were used interchangeably (Alma 53:3).

The Sorenson model identifies the city of Bountiful as being in the area of the current city of Tonalá, which is located on the west bank of the Tonalá River prior to it discharging into the Gulf of Mexico, with an approximate longitude/latitude location of 18° 12’ 16” N and 94° 08’ 41” W. This location does lie within the Mercalli zone 8 area, however it is located on stable bedrock consisting of conglomerate, sandstone, and siltstone formations, which may have dampened surface oscillations somewhat limiting the earthquake damage (see figure 60).

Importantly, directly across the Tonalá River is an entirely different seismic situation, as the soils and sediment are marsh deposits that are extremely susceptible to amplified ground shaking and potential liquefaction. The estimate for the amplification increase for this material, which extends for kilometers eastward and southward, is that it would add 2.4 points to the Mercalli scale, making the level 8 intensity estimated for the area a 10.4 (see figure 60). The destruction description for level 10 and 11 intensity is:

> 10. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
>
> 11. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

The identification of Bountiful located at Tonalá under the Sorenson model is directly supported by the underlying geology and the regional earthquake scenario. The indication that Bountiful exhibited a much lower level of damage than areas immediately adjacent is supported by the underlying stable rock where Bountiful is, and is also supported by the extensive damage caused by the earthquake amplification in the marsh alluvial deposits that would have occurred within sight easterly across the river for long distances east and south. This clearly squares with the people “marveling and wondering” and “were showing one with another the great and marvelous change which had taken place.” No doubt some of the wonder would have been caused by seeing the relative difference in levels of destruction from one side of the river to the other.

Also, since the earthquake would be stronger (even in the stable rock) further to the south and west, this location for Bountiful would have received the lowest intensities of the earthquake anywhere north of the Veracruz fault, as it was the farthest point away from the fault before encountering soils and sediments that significantly amplify the earthquake shaking. It would have been the area of least damage in the region where people might logically gather after a large earthquake.

The Tonalá location is an absolute best fit for the city of Bountiful.

Events Without Geographic Specificity

There are a number of events in the prophecies and in 3rd Nephi that do not have geographic specificity, but they also have best fit explanations as to the geologic event that they are linked to, so in that sense are tied to geography. These events can be analyzed with best fit analysis, but for the most part they are all explained by volcanic eruption or by a regional earthquake.

Noises

The 3rd Nephi account references three types of noises: (1) terrible thunder that occurred for three hours, (2) tumultuous noises that occurred for three days, and (3) dreadful groanings that occurred for three days. The best fit for all of these is a volcanic eruption coupled with a regional earthquake and aftershocks.

—Terrible thunder

The "terrible thunder" occurred initially and during the first three hours of the catastrophe with the clear best fit being the initial explosive events of the volcanic eruption. Besides the noise of the explosions, upon initial eruption, volcanoes produce an initial pressure or shock wave. When Mount St. Helens erupted, the pressure wave preceded the initial blast and the blast was described as a "roaring noise" (Rosenbaum et al., 1981).

The terrible thunder was also referenced as part of the force that caused the whole face of the land northward to be changed, so by implication it was part of the volcanic eruption. Secondarily, earthquakes can also create sonic booms in some geologic settings (discussed further in chapter 13).

—Tumultuous Noises and Dreadful Groanings

"All manner of tumultuous noises" are mention as continuing, at least intermittently, for three days as well as "dreadful groanings." The range of noises that can be created by a volcanic eruption range across a broad sound spectrum from whistles, jetting, and hissing from the escape of subterranean gases to rumbles from debris avalanches to harmonious sounds that develop in lava tubes to loud explosions from ongoing eruptive release. Scientists have characterized the captivating diversity of acoustics generated from outgassing and fluid dynamic processes as a "volcanic symphony" (Garces et al., 2013, 368). This range of noise would clearly encompass the description of "tumultuous noises" and "dreadful groaning" referred to in 3rd Nephi.

As previously mentioned, the 1793 San Martín volcanic eruption produced around 400 phreatomagmatic explosions, which the inhabitants mistook as cannon fire. Ironically, even though cannon fire was clearly not a part of the Book of Mormon, when the Book of Mormon quotes Isaiah, the term "tumultuous noises" is used to describe the noise of gathering and mustering for battle.

> The noise of the multitude in the mountains like as of a great people, a tumultuous noise of the kingdoms of nations gathered together, the Lord of Hosts mustereth the hosts of the battle. 2 Nephi 23:4

The term “tumultuous noises” is used in one other place in the Book of Mormon, involving another volcanic event that is discussed in further in chapter 13.

> And it came to pass when they heard this voice, and beheld that it was not a voice of thunder, neither was it a voice of a great tumultuous noise, but behold, it was a still voice of perfect mildness, as if it had been a whisper, and it did pierce even to the very soul. Helaman 5:30

Earthquakes can also create a small variety of noises as compared to a volcano. Most earthquake seismic wave sounds are below the audible range for humans. Except for the sonic booms that can accompany earthquakes, most of the sounds associated with earthquakes are described as low rumbles or the sound of grating rocks. These sounds might better fit into the “dreadful groaning” category.

Exceeding Sharp Lightening

Without having witnessed a volcanic eruption, one might seek to explain the reference to “exceeding sharp lightening” by a severe thunderstorm, however the nature of volcanic lightning is something to behold and very clearly is the best fit based on the Book of Mormon description, with the statement that it had “never had been known in all the land” definitely not an exaggeration. Figures 78 and 79 demonstrate the nature of this lightening. Even though there is some time lapse as part of the photography, the volcanic lightening is awe-inspiring, and would truly strike fear in anyone who witnessed it.

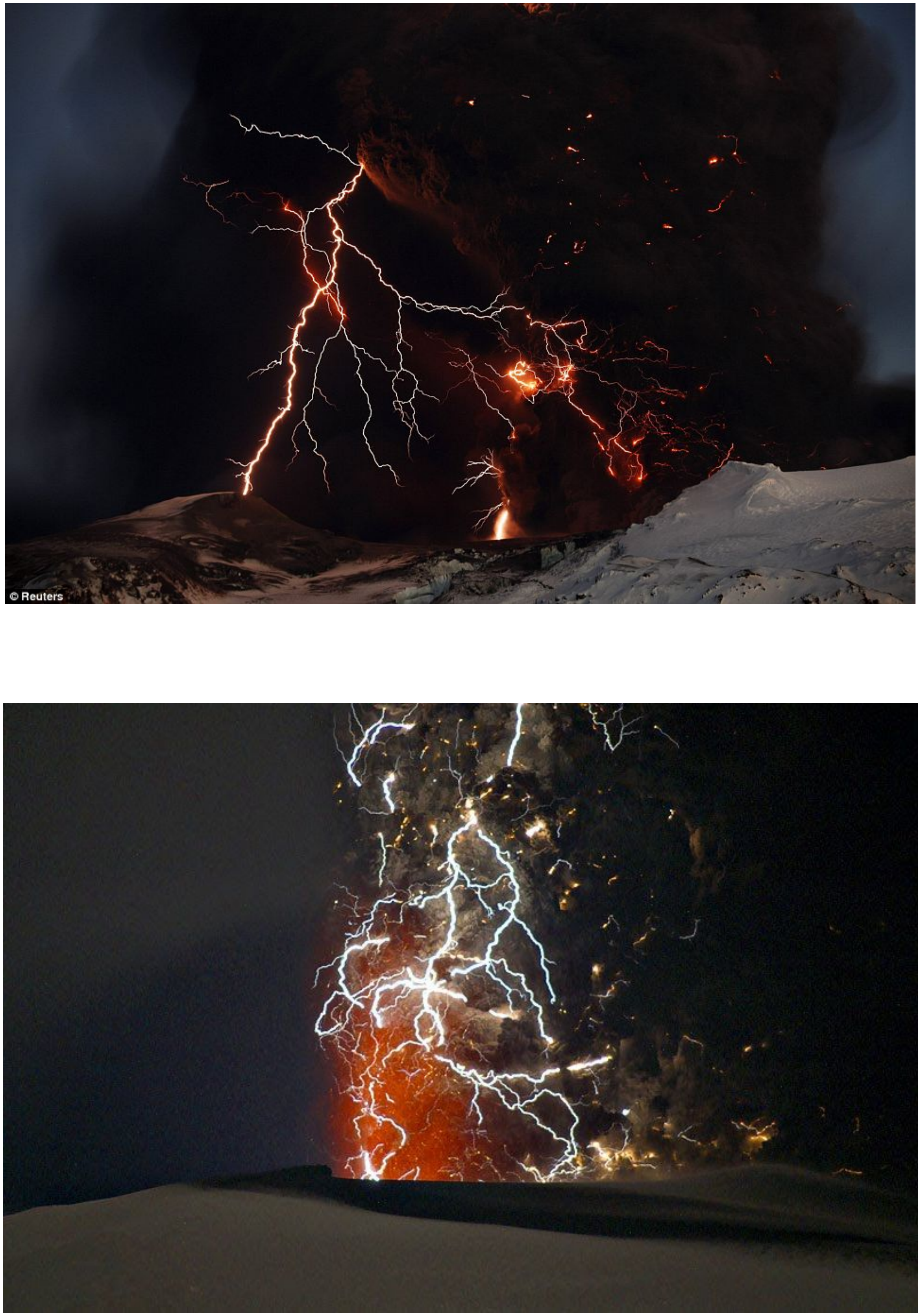


Figure 78. Volcanic lightning from the Eyjafjallajokull, Iceland, volcano, April 2010 (courtesy Reuters)

Figure 79. Volcanic lightning from the June 2011 eruption of the Cordón Caulle volcano in Chile (courtesy Negroni, 2014)

Figure 79 continued. Volcanic lightning from the June 2011 eruption of the Cordón Caulle volcano in Chile (courtesy Negroni, 2014)

Earthquake Related Events

The following events mentioned in the 3rd Nephi account can be related to a regional earthquake, but do not have any other specific geographic tie. The best fit for this occurrence is within the Mercalli intensity 8 zone shown in figure 61.

- Mountains tumbling into pieces
- Earth trembling (3-day duration, earthquake aftershocks)
- Rocks rend
- Earth rent
- Earth cleaved together
- Opening of the earth
- Face of the land changed
- Breaking up and scattering of rocks

Volcanic Eruption Related Events

The following events mentioned in the 3rd Nephi account can be related to a volcanic eruption, but do not have any other specific geographic tie. The best fit for this occurrence is a location within the "hills and valleys" area shown in figure 76.

- Mountains tumbling into pieces
- Earth trembling (3-day duration, earthquake aftershocks)
- Rocks rend
- Earth rent
- Earth cleaved together
- Opening of the earth
- Breaking up and scattering of rocks
- Opening of the earth
- Fire and smoke
- Face of the land changed

Mountains Made Low "Like unto a Valley"; Valleys Which Shall Become Mountains

The method by which valleys become mountains was previously discussed in the section on the city of Moronihah. The description of mountains made low "like unto a valley" can be explained either by (1) a volcanic debris avalanche, which involves the collapse of a volcano during eruption or of a weakened weathered volcanic deposit or by (2) a large landslide. Of particular interest is the description "like unto a valley." The language is different than merely referring to them as a valley, because the landform being described is not quite like a normal valley. This description is quite accurate as the valleys that result from both the volcanic avalanche and a large landslide are not exactly valleys, as they have a headwall on the upper slope and the valley that forms is somewhat of a U-shape instead of a classic V-shaped riverine valley and are often referred to as landslide scarps. An example of a collapsed volcanic cone is shown in figure 80; this type of horseshoe-shaped valley landform is typical. Geographically, the best fit for this occurrence is a location within the "hills and valleys" area shown in figure 76. An example of a something "like unto a valley" formed from a landslide is shown in figure 81. The best fit for this occurrence is within the Mercalli intensity 8 zone shown in figure 61.

Figure 80. Debris avalanche scarp of White Island Volcano, New Zealand (courtesy http://wikitravel.org, 2014)

Figure 81. Landslide scarp from 1995 La Conchita, California, landslide (courtesy National Geophysical Data Center, NOAA, http://www.ngdc.noaa.gov/hazardimages/picture/show/1562)

Chapter 13

Other Earthquake and Volcanic Events

Land of Nephi Volcano Event

An apparent volcanic event takes place in the Book of Mormon around 30 BC when two individuals, Nephi and Lehi, are imprisoned because their religious teachings were not well received by the local religious and political powers. The geographical location of the prison is determined by a reference at Helaman 5:21 that identifies the prison as the same one where Ammon and his brethren were imprisoned by the servants of Limhi (Mosiah 7:5–8). By this reference we are able to determine that the prison was located in the land of Nephi, which is adjacent to the land of Shilom. The relevant scriptures relating the incident as well as the earlier Mosiah incident are cited here:

Helaman 5:20–49

> 20. And it came to pass that Nephi and Lehi did proceed from thence to go to the land of Nephi.
>
> 21. And it came to pass that they were taken by an army of the Lamanites and cast into prison; yea, even in that same prison in which Ammon and his brethren were cast by the servants of Limhi.
>
> 22. And after they had been cast into prison many days without food, behold, they went forth into the prison to take them that they might slay them.
>
> 23. And it came to pass that Nephi and Lehi were encircled about as if by fire, even insomuch that they durst not lay their hands upon them for fear lest they should be burned. Nevertheless, Nephi and Lehi were not burned; and they were as standing in the midst of fire and were not burned.
>
> 24. And when they saw that they were encircled about with a pillar of fire, and that it burned them not, their hearts did take courage.
>
> 25. For they saw that the Lamanites durst not lay their hands upon them; neither durst they come near unto them, but stood as if they were struck dumb with amazement.
>
> 26. And it came to pass that Nephi and Lehi did stand forth and began to speak unto them, saying: Fear not, for behold, it is God that has shown unto you this marvelous thing, in the which is ~~shown~~ [shewn] unto you that ye cannot lay your hands on us to slay us.
>
> 27. And behold, when they had said these words, the earth shook exceedingly, and the walls of the prison did shake as if they were about to tumble to the earth; but behold, they did not fall. And behold, they that were in the prison were Lamanites and Nephites ~~who~~ [which] were dissenters.
>
> 28. And it came to pass that they were overshadowed with a cloud of darkness, and an awful solemn fear came upon them.

29. And it came to pass that there came a voice as if it were above the cloud of darkness, saying: Repent ye, repent ye, and seek no more to destroy my servants whom I have sent unto you to declare good tidings.

30. And it came to pass when they heard this voice, and beheld that it was not a voice of thunder, neither was it a voice of a great tumultuous noise, but behold, it was a still voice of perfect mildness, as if it had been a whisper, and it did pierce even to the very soul--

31. And notwithstanding the mildness of the voice, behold the earth shook exceedingly, and the walls of the prison trembled again, as if it were about to tumble to the earth; and behold the cloud of darkness, which had overshadowed them, did not disperse--

32. And behold the voice came again, saying: Repent ye, repent ye, for the kingdom of heaven is at hand; and seek no more to destroy my servants. And it came to pass that the earth shook again, and the walls trembled.

33. And also again the third time the voice came, and did speak unto them marvelous words which cannot be uttered by man; and the walls did tremble again, and the earth shook as if it were about to divide asunder.

34. And it came to pass that the Lamanites could not flee because of the cloud of darkness which did overshadow them; yea, and also they were immovable because of the fear which did come upon them.

35. Now there was one among them who was a Nephite by birth, who had once belonged to the church of God but had dissented from them.

36. And it came to pass that he turned him about, and behold, he saw through the cloud of darkness the faces of Nephi and Lehi; and behold, they did shine exceedingly, even as the faces of angels. And he beheld that they did lift their eyes to heaven; and they were in the attitude as if talking or lifting their voices to some being whom they beheld.

37. And it came to pass that this man did cry unto the multitude, that they might turn and look. And behold, there was power given unto them that they did turn and look; and they did behold the faces of Nephi and Lehi.

38. And they said unto the man: Behold, what do all these things mean, and who is it with whom these men do converse?

39. Now the man's name was Aminadab. And Aminadab ~~said~~ [saith] unto them: They do converse with the angels of God.

40. And it came to pass that the Lamanites said unto him: What shall we do, that this cloud of darkness may be removed from overshadowing us?

41. And Aminadab said unto them: You must repent, and cry unto the voice, even until ye shall have faith in Christ, ~~who~~ [which] was taught unto you by Alma, and Amulek, and Zeezrom; and when ye shall do this, the cloud of darkness shall be removed from overshadowing you.

> 42. And it came to pass that they all did begin to cry unto the voice of him ~~who~~ [which] had ~~shaken~~ [shook] the earth; yea, they did cry even until the cloud of darkness was dispersed.
>
> 43. And it came to pass that when they cast their eyes about, and saw that the cloud of darkness was dispersed from overshadowing them, behold, they saw that they were encircled about, yea every soul, by a pillar of fire.
>
> 44. And Nephi and Lehi ~~were~~ [was] in the midst of them; yea, they were encircled about; yea, they were as if in the midst of a flaming fire, yet it did harm them not, neither did it take hold upon the walls of the prison; and they were filled with that joy which is unspeakable and full of glory.
>
> 45. And behold, the Holy Spirit of God did come down from heaven, and did enter into their hearts, and they were filled as if with fire, and they could speak forth marvelous words.
>
> 46. And it came to pass that there came a voice unto them, yea, a pleasant voice, as if it were a whisper, saying:
>
> 47. Peace, peace be unto you, because of your faith in my Well Beloved, ~~who~~ [which] was from the foundation of the world.
>
> 48. And now, when they heard this they cast up their eyes as if to behold from whence the voice came; and behold, they saw the heavens open; and angels came down out of heaven and ministered unto them.
>
> 49. And there were about three hundred souls who saw and heard these things; and they were ~~bidden~~ [bid] to go forth and marvel not, neither should they doubt.

Mosiah 7:5–8

> 5. And when they had wandered forty days they came to a hill, which is north of the land of Shilom, and there they pitched their tents.
>
> 6. And Ammon took three of his brethren, and their names were Amaleki, Helem, and Hem, and they went down into the land of Nephi.
>
> 7. And behold, they met the king of the people ~~who were~~ [which was] in the land of Nephi, and in the land of Shilom; and they were surrounded by the king's guard, and ~~were~~ [was] taken, and ~~were~~ [was] bound, and ~~were~~ [was] committed to prison.
>
> 8. And it came to pass when they had been in prison two days they were again brought before the king, and their bands were loosed; and they stood before the king, and ~~were~~ [was] permitted, or rather commanded, that they should answer the questions which he should ask them.

Natural Event Analysis

It does not appear possible to explain all of the phenomena of this event with natural causes. Specifically, the "flaming fire" that did not burn anything has no known natural explanation that I am aware of. The description of the fire did at least indicate that the walls of the prison were constructed of wood or other flammable material, noting the witnesses' surprise that the fire "did not take hold on the walls of the prison" as was expected.

The other events that occurred considered together have all the hallmarks of a mild volcanic eruption, which would typically include an earthquake corresponding with the start of the eruption, and then a series of mild earthquakes of similar size spaced over the period of the eruption. The possibility that a volcanic eruption is an explanation for this event has been noted in a general way by Brant Gardner (2007, 93–94), but no attempt was made to identify the specific mechanisms or location. Specifically, after the fire appeared, the sequence of events was:

1. First earthquake
2. Overshadowing cloud of darkness appeared
3. Second earthquake
4. Third earthquake
5. Cloud of darkness dissipated

No time periods are provided for each of these events, but based on what was going on, it appeared to be more than an hour. Each of the earthquakes appeared to be of similar intensity, each earthquake was strong enough to cause the walls to "tremble" but not sufficient to cause the walls to "tumble to the earth" even though the witnesses thought they might.

An earthquake with an intensity of Level IV on the Modified Mercalli scale is described as:

> Felt indoors by many to all people, and outdoors by few people. Some awakened. Dishes, windows, and doors disturbed, and walls make cracking sounds. Chandeliers and indoor objects shake noticeably. The sensation is more like a heavy truck striking building. Standing automobiles rock noticeably. Dishes and windows rattle alarmingly. Damage none.

An earthquake with an intensity of Level V on the Mercalli scale is described as:

> Felt inside by most or all, and outside. Dishes and windows may break and bells will ring. Vibrations are more like a large train passing close to a house. Possible slight damage to buildings. Liquids may spill out of glasses or open containers. None to a few people are frightened and run outdoors.

An earthquake with an intensity of Level VI on the Mercalli scale is described as:

> Felt by everyone, outside or inside; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight to moderate to poorly designed buildings, all others receive none to slight damage.

The Mercalli scale was developed assuming modern construction techniques; most ancient structures would probably fall into the modern day classification as "poorly designed buildings."

Based on the Mercalli scale, it appears that the earthquakes were probably between a IV and V, based on the fact that the prison was not actually damaged, but appeared to be close to the level where damage might have begun. A number of 4.5 would seem reasonable.

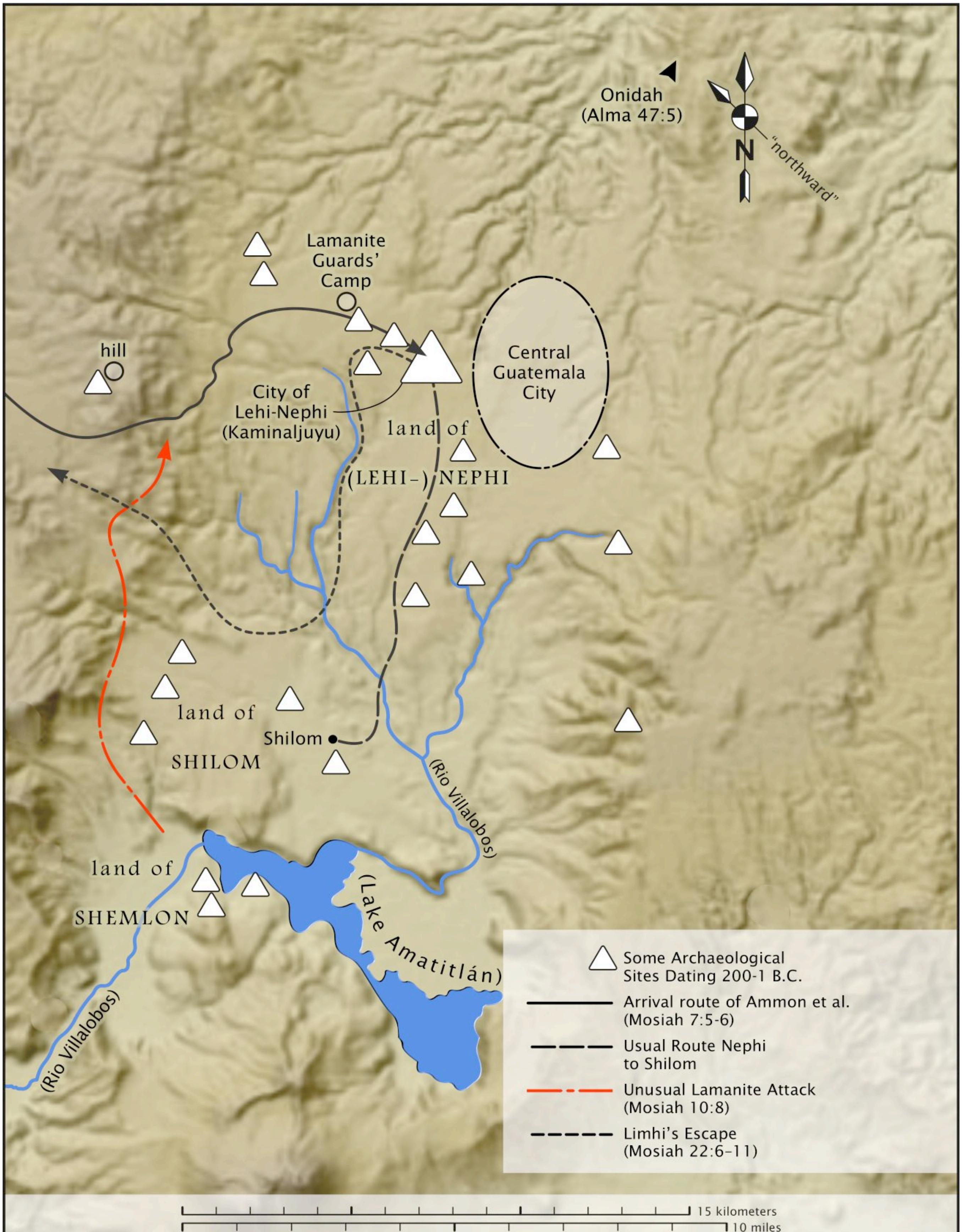


Figure 82 – Location of the Land of Nephi and Shilom in the Sorenson Model

Comparison with Sorenson Model

Sorenson has identified the Land of Nephi to be located in the area of the current Guatemala City, north of Lake Amatitlan (see figure 82). Just south of Lake Amatitlan is the volcano Pacaya. Also to the west is the volcano Aqua, which has not been historically active. Pacaya (figure 83) is a volcanic complex that is currently active, and has been so quite frequently historically. It is an excellent candidate for the source and cause of the incident at the prison in the Land of Nephi. Pacaya has produced both large scale and mild volcanic eruptions in modern times. Pacaya has exhibited eruptions from the cone as well as eruptions on its flanks.

A mild eruptive event in May of 1998 produced an ash cloud that traveled north to Guatemala City that mirrors the “cloud of darkness” event that occurred in 30 AD. Figure 84 is an ‘isopach’ map that shows the depositional thickness of the ash cloud.

Figure 83. Pacaya Volcano November 1988 (Smithsonian, 2014)

With regards to the series of earthquakes that occurred in 30 BC, it would be useful to calculate their approximate magnitude to see if they are consistent with a volcanic earthquake generated by either Pacaya or Aqua.

Using an intensity of 4.5 on the Mercalli scale, we can back-calculate the magnitude of the earthquake using the Zobin formula previously discussed.

$I = 0.66M_w – 1.13LogR – 0.0072R + 3.73$

I : Intensity in Modified Mercalli

R : the distance away from the hypocentral point of the earthquake (the point on the surface immediately above the earthquake epicenter).

M_w: Intensity in Moment Magnitude Scale at the volcano

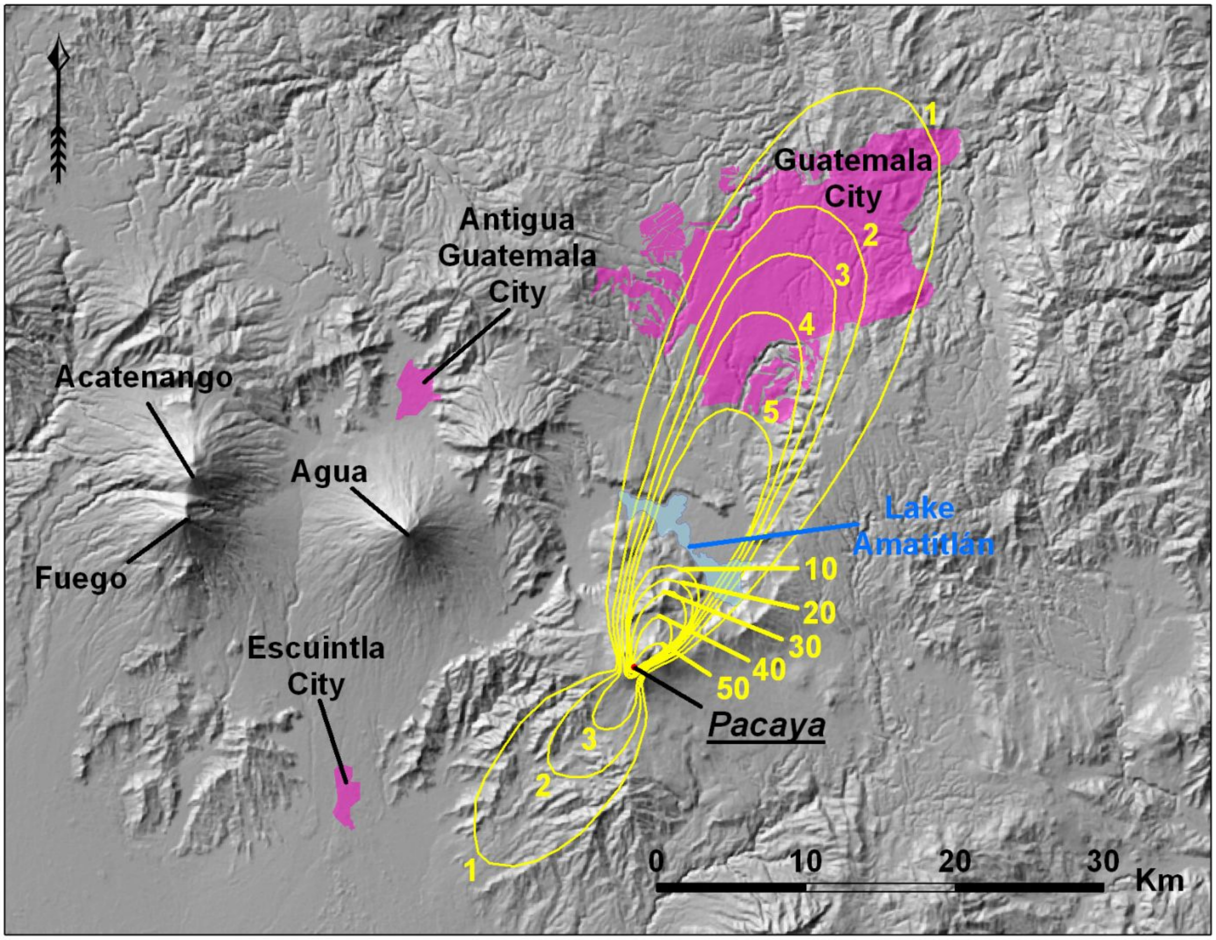


Figure 84. Isopach map associated to the volcanic event of May 20, 1998. The values of the isopachs (in yellow) are given in millimeters. The names of other volcanoes and populated centers (in pink), as well as the lakes (in blue) are also given. (Gomez, 2009, 31)

The distance from the summit cone of either the Pacaya or the Agua volcano to some of the southern archealogical sites in land of Nephi is approximately 17 kilometers, the distance from a potential flank eruption is 15 kilometers. The distance to the central archeological sites is approximately 24 kilometers. As the exact location of the prison is not known, there will be some potential variability, but not much. Using these parameters, the magnitudes of the volcanic earthquakes that occurred in 30 BC are between 3.3 M_w and 3.8 M_w, which is precisely in the common magnitude range of volcanic eruption earthquakes.

With regards to the land of Nephi as placed in Sorenson's model, the surrounding geology is highly corroborative.

Ammonihah Earthquake Event

About 81 BC, another event involving an earthquake and a prison took place in the city of Ammonihah. This event involves one very strong earthquake event, appearing to be a Level VIII on the Modified Mercalli scale. The recounting of the event in the Book of Mormon is as follows:

Alma 14:25–29

> 25. And it came to pass that they all went forth and smote them, saying the same words, even until the last; and when the last had spoken unto them the power of God was upon Alma and Amulek, and they ~~rose~~ [arose] and stood upon their feet.
>
> 26. And Alma cried, saying: How long shall we suffer these great afflictions, O Lord? O Lord, give us strength according to our faith which is in Christ, even unto deliverance. And they ~~broke~~ [break] the cords with which they were bound; and when the people saw this, they began to flee, for the fear of destruction had come upon them.
>
> 27. And it came to pass that so great was their fear that they fell to the earth, and did not obtain the outer door of the prison; and the earth shook mightily, and the walls of the prison were rent in twain, so that they fell to the earth; and the chief judge, and the lawyers, and priests, and teachers, ~~who~~ [which] smote upon Alma and Amulek, were slain by the fall thereof.
>
> 28. And Alma and Amulek came forth out of the prison, and they were not hurt; for the Lord had granted unto them power, according to their faith which was in Christ. And they straightway came forth out of the prison; and they were loosed from their bands; and the prison had fallen to the earth, and every soul [which was] within the walls thereof, save it were Alma and Amulek, ~~was~~ [were] slain; and they straightway came forth into the city.
>
> 29. Now the people having heard a great noise came running together by multitudes to know the cause of it; and when they saw Alma and Amulek coming forth out of the prison, and the walls thereof had fallen to the earth, they were struck with great fear, and fled from the presence of Alma and Amulek even as a goat fleeth with her young from two lions; and thus they did flee from the presence of Alma and Amulek.

Sorenson's model identifies the location of Ammonihah as the ruins at Mirador, Chiapas, Mexico. Mirador is located at approximately latitude 16° 39' 50" longitude 93° 34' 37" north of the town of Colonia Vicente Guerrero (see figure 86). The ruins at Mirador sit at the northwestern boundary of the strike-slip Fault province of the Sierra de Chiapas. The El Brillante-Uzpanapa strike-slip fault lies 3 km north of Mirador, the Quintana Roo strike-slip fault sits 7 km to the southwest (El Servicio Geológico Mexicano, 2005). The area is currently an active earthquake zone. Very recent activity includes an earthquake of magnitude 5.0_w occurred on January 20, 2011 4.0 kilometers to the northwest of the site at a depth of 154 kilometers on the El Brillante-Uzpanapa fault. Another earthquake at depth along the fault 7.0 kilometers to the southeast was recorded April 02, 2008, with a magnitude of 4.1_w at a depth of 180 kilometers on an unidentified fault (ANSS, 2014).

Figure 85 – Ammonihah Location in the Sorenson Model

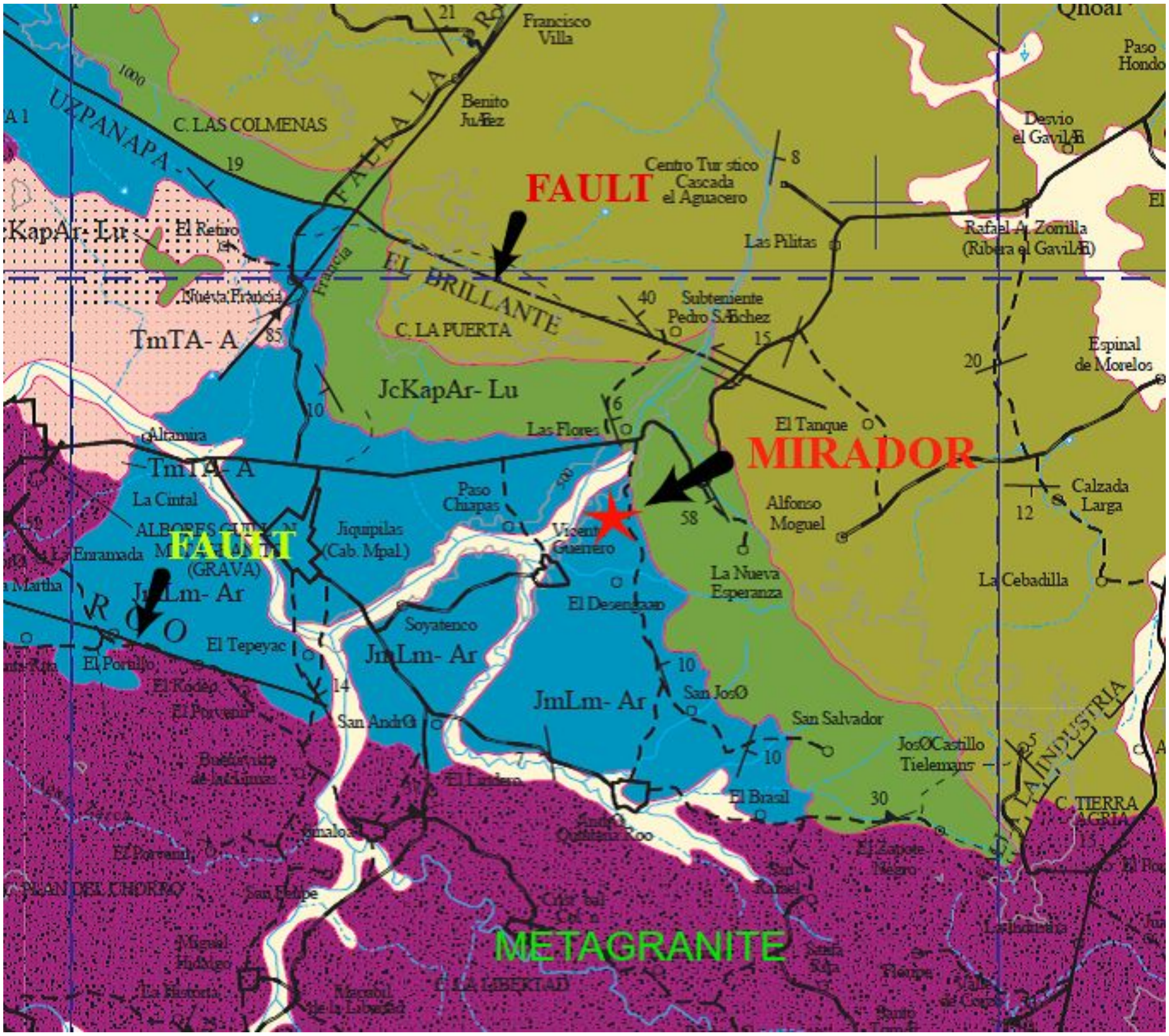


Figure 86. Geologic map of Mirador area; pink stipple formation is metagranite, which underlies layered sedimentary formations (blue, green, olive) (El Servicio Geológico Mexicano, 2005)

Also of interest is the indication that the people heard a “great noise” and came running together. A phenomenon that has been historically identified as an “earthquake boom” is indicated here. The inner workings of earthquakes that cause earthquake booms, called supershear earthquakes, which break the seismic sound barrier creating a sonic boom, have been confirmed in laboratory experiments using granite under controlled upper-crustal stress conditions (Passelègue et al., 2013). Supershear earthquakes are events in which the rupturing fault breaks faster than certain seismic waves can travel, creating a seismic mach cone that fires out the end of a fault's rupture zone. That cone and the waves that follow can cause inordinately severe shaking, out of proportion to the earthquake's magnitude. These earthquakes have been observed almost exclusively in strike-slip faults because of higher rupture speeds that occur with strike-slip faulting (Wang et al., 2013). Incidentally, the geologic formation at depth beneath Ammonihah is a Paleozoic metagranite, which seems to correlate nearly exactly to the laboratory experiments recently performed using granite to generate supershear "sonic boom" earthquakes (see figure 86).

The description of the event at Ammonihah in the location proposed by Sorenson is entirely plausible, in terms of both the earthquake magnitude standpoint and the sonic boom ("great noise") that was heard at the time of the earthquake, probably emanating from the underlying metagranite formation and the fault. The site sits in an active earthquake zone sufficient to generate earthquakes of intensities greater than Level VIII on the Mercalli scale, which is the level indicated for collapse of the prison. The site has proximity to some major faults, a subduction zone at depth, and recent recorded earthquakes. The fact that the earthquake involved a sonic boom may have set this particular quake apart from others common to the area, coupled with the collapse of the prison and death of their political and religious leaders with only Alma and Amulek emerging, would have been ample cause to be "struck with great fear."

Jaredite Geologic Events

The record of the Jaredites as contained in the book of Ether does not indicate direct geologic events. However, there are two natural disasters described that might lend themselves, at least in part, to geologic events.

In Ether chapter 9 when Heth was the ruler, a description of a dearth on the land involving a significant ecosystem disruption is given:

Ether 9:29–35

> 29. But the people believed not the words of the prophets, but they cast them out; and some of them they cast into pits and left them to perish. And it came to pass that they ~~did~~ [done] all these things according to the commandment of the king, Heth.
>
> 30. And it came to pass that there began to be a great dearth upon the land, and the inhabitants began to be destroyed exceeding~~ly~~ fast because of the dearth, for there was no rain upon the face of the earth.
>
> 31. And there came forth poisonous serpents also upon the face of the land, and did poison many people. And it came to pass that their flocks began to flee before the poisonous serpents, towards the land southward, which was called by the Nephites Zarahemla.
>
> 32. And it came to pass that there were many of them which did perish by the way; nevertheless, there were some which fled into the land southward.
>
> 33. And it came to pass that the Lord did cause the serpents that they should pursue them no more, but that they should hedge up the way that the people could not pass, that whoso should attempt to pass might fall by the poisonous serpents.
>
> 34. And it came to pass that the people did follow the course of the beasts, and did devour the carcasses of them which fell by the way, until they had devoured them all. Now when the people saw that they must perish they began to repent of their iniquities and cry unto the Lord.

35. And it came to pass that when they had humbled themselves sufficiently before the Lord ~~he~~ [the Lord] did send rain upon the face of the earth; and the people began to revive again, and there began to be fruit in the north countries, and in all the countries round about. And the Lord did show forth his power unto them in preserving them from famine.

Ether 10:18–19

18. And it came to pass that Kish passed away also, and Lib reigned in his stead.

19. And it came to pass that Lib also did that which was good in the sight of the Lord. And in the days of Lib the poisonous serpents were destroyed. Wherefore they did go into the land southward, to hunt food for the people of the land, for the land was covered with animals of the forest. And Lib also himself became a great hunter.

Ether 11 describes references “famines and pestilences” and “a great destruction,” “such an one as never had been upon the face of the earth”:

Ether 11:5–7

5. And it came to pass that the brother of ~~Shiblom~~ [Shiblon] ~~caused~~ [did cause] that all the prophets who prophesied of the destruction of the people should be put to death;

6. And there was great calamity in all the land, for they had testified that a great curse should come upon the land, and also upon the people, and that there should be a great destruction among them, such an one as never had been upon the face of the earth, and their bones should become as heaps of earth upon the face of the land except they should repent of their wickedness.

7. And they hearkened not unto the voice of the Lord, because of their wicked combinations; wherefore, there began to be wars and contentions in all the land, and also many famines and pestilences, insomuch that there was a great destruction, such an one as never had been known upon the face of the earth; and all this came to pass in the days of ~~Shiblom~~ [Shiblon].

Unlike the rest of the Book of Mormon, the Jaredite record does not contain calendar markers to show precisely when these natural disasters took place. Based on generational counts, and using a generic lifespan with some assumptions, Sorenson (1985) and Palmer (1982, 128) place the approximate dates of these events as:

Sorenson

Severe drought   2300 BC to 2200 BC

War, famine, destruction   1050 BC to 900 BC

Palmer

Potential rule of Heth   2230 BC to 2090 BC

Potential rule of Shiblon   1070 BC to 940 BC

Location of Jaredite Lands

Virtually all Mesoamerica Book of Mormon geographical models identify the Jaredites as part of the Olmec culture. The geographical lands of the Jaredites are illustrated in figure 87 (Sorenson's map 11 from *Mormon's Codex*).

Volcanic Events during Jaredite Natural Disaster Time Frames

Volcanic eruptions have been implicated in serious disruptions to local ecology and civilizations. In determining whether volcanic activity may have had a role in the Jaredite natural disasters it is necessary to evaluate the volcanic history of volcanoes in or adjacent to Jaredite lands to see if there are any correlations. The potential volcanoes in or adjacent to Jaredite lands are San Martín, Pico de Orizaba, Las Cumbres, El Chichón, and the Naolinco Volcanic Field.

Radiocarbon dating has shown the activity of these volcanoes during or close to the proposed natural disaster time frames to be:

Disaster during Heth rule

Las Cumbres
1970 BC ± 50 years**

El Chichón
2030 BC ± 100 years** (Tephra Unit K)

Pico de Orizaba
2110 BC ± 50 years**
2300 BC ± 75 years**

San Martín
2130 BC ± 50 years**
2308 BC to 2198 BC*

Disaster during Shiblon rule

Naolinco Volcanic Field
1200 BC ± 50 years**

San Martín
1320 BC ± 300 years**
1470 BC to 1160 BC***

*Sieron et al., (2014)
**Smithsonian (2014)
***Riveron et al., (2009), Santley (2007)

The volcanic eruption data does show multiple volcanic eruptions from multiple volcanoes occurring in and immediately adjacent to Jaredite lands.

Figure 87 – Jaredite Lands in the Sorenson Model

Book of Mormon/Jaredite Climate Compared with Scientific Determinations of Paleoclimate

The climatic history of a region can be determined by a variety of methods, including pollen studies that reveal changing plant assemblages related to climatic changes, and investigations of the relative abundance and fossil assemblages of diatoms, phytoliths, and foraminifera. More direct indicators of specific climatic parameters such as precipitation and temperature can be derived from isotopic examinations, particularly the $\delta\ ^{18}O$ ratio of marine cores and ostracod/gastropod shells extracted from closed basin lakes. Stratigraphic geochemical and lake level analyses can also be utilized to understand larger scale climatic patterns.

Studies in the Caribbean region utilizing these methods include Lake Miragoane, Haiti (Hodell et al., 1991; Higuera-Gundy et al., 1999), and Lake Valencia, Venezuela (Bradbury et al., 1981, Leyden, 1985, Curtis et al., 1999) with other correlations coming from studies in Floridian sinkholes (Watts and Hansen, 1994), Peten in northeast Guatemala (Leyden, 1984), and Lake La Yeguada, Panama (Piperno et al., 1989).

The Caribbean regional data indicates a dry period correlating to the late Pleistocene (approximately 9750 BC), followed by increased precipitation and temperature levels, with the period of maximum precipitation occurring from the early to mid Holocene (approximately 3900 BC), followed by a return to significantly dryer conditions after 1250 BC, with the level of aridity increasing again at 450 BC. The Heth event time frame (2300–2090 BC) is not inconsistent with the climatological data in that it did not occur at a period of high precipitation, however it does appear that the drought during this time period was caused or exacerbated by local climatological conditions as there is no indication of a regional increase in aridity. The Shiblon event time frame (1070–900 BC) does correspond with the dry conditions that were initiated after 1250 BC, so does not necessarily indicate a drought caused by local environmental conditions.

Local Climatological Effects of a Volcanic Eruption

It has long been recognized that volcanic eruptions affect worldwide climate by the injection of aerosols into the stratosphere (Franklin, 1974, Fong-Chiau et al., 2003) and can cause droughts or significant cooling on a regional scale far from the volcanic eruption. Sorenson (2013), citing other sources, noted the local effects of volcanic eruptions in Mesoamerica. This included the work of Gill and Keating (2002) that found a highly statistical correlation in Mesoamerica between large volcanic eruptions anywhere in the world with drought and subsequent famine. In addition, it has recently been recognized that the local ground level emissions from volcanic eruptions can cause localized droughts because the reactions of local emissions, SO_2, and other volcanic gases in the local atmosphere can suppress rainfall by inhibiting raindrop formation (USGS, 2001).

On a local level, Sorenson (2013) also noted that the 1902 eruption of the Santa Maria volcano in Guatamala killed all of the birds for hundreds of miles around, with the result that “flies, mosquitos, and rats [multiplied] to such an extent that life for human beings became nearly unbearable” because of illnesses (Dull, 2001). Moziño (1870) reported a similar effect on wild birds as a result one of the smaller eruptive events during the 1793 eruption of the San Martín volcano, in that they were stunned and immobilized such that they could be collected by hand.

Dull also noted that:

> Although post- eruption starvation and disease have caused only 4 percent of the volcano-related deaths worldwide since 1900, this percentage swells dramatically to 49 percent for the pre-industrial period from 1600 to 1899. . . .
>
> Thus, malnutrition, starvation, and pestilence following the TBJ (260 AD Tierra Blanca Joven eruption of the Ilopango caldera in central El Salvador) eruption might have been partly responsible for progressive demographic collapse throughout the abandonment zone.

Sorenson (2013), citing other authors, recounts the noxious effects on human health from the eruption's volcanic ash and gases, and notes the contamination of water supplies by ashfall, essentially stopping agricultural production. Moziño also reported with regards to the 1793 San Martín eruption, that there was fish kill and clogging of the Tuxtla River with mud and sand, with the drinking of the murky water the cause of "many grave cases of dysentery and persistent coughing."

Analysis of 2300 to 2090 BC Jaredite Natural Disaster Event ("Heth Event")

The Heth Event in the book of Ether can be summarized chronologically as follows:

1. Great dearth upon the land
2. Inhabitants destroyed exceedingly fast because of the dearth; there was no rain on the face of the earth
3. Poisonous serpents came forth and poisoned many people
4. Flocks flee 'before' the poisonous serpents towards the land southward
5. Some of the animals perished along the way; some made it into the land southward
6. Serpents stopped pursuit, hedged up a way so people could not pass without falling to the poisonous serpents
7. People followed the path of the animals, eating all of the ones that had fallen
8. Rain came back to the earth
9. Sometime later the serpents were destroyed so people could pass to the land southward

In the Jaredite/Olmec homeland area there are 5 types of poisonous snakes; coral snakes, fer-de-lances (pit vipers), cantils, eyelash vipers, and regionally located pit vipers. There are two varieties of coral snakes, the variable coral snake and the elegant coral snake. The 5 types of regional pit vipers are the jumping pit viper, the Olmecan pit viper, the hog nosed pit viper, Dunn's hog-nosed pit viper, and Rowley's palm pit viper.

Coral snakes prefer wooded areas, marshes, or places with loose soil. Coral snakes remain in their dens for the majority of the day and are rarely spotted by humans during the day. Unlike many other snakes, the coral snake is not bold and will try to flee a situation rather than stand its ground. If the animal feels harassed, however, it may strike without warning.

The Mexican cantil occurs in a vast range of habitats, including seasonally dry forest, tropical deciduous forest, tropical scrub forest, and savanna. Habitat bordering rivers or streams is preferred, but it may also occur in grasslands and cultivated lands. They are generally shy by nature, and if threatened their first instinct is to rely on camouflage. If unable to do so they will use a threat display to ward off potential predators. The tightly coiled animal will raise the last several inches of its tail, this portion often being bright yellow or green in juveniles and a faded yellow or green in adults, the animal will then quickly flick its tail creating a loud whipping sound against its coils or surroundings. They generally will only display these behaviors when given no other choice.

The eyelash viper prefers lower altitude, humid, tropical areas with dense foliage, generally not far from a permanent water source. It lives in trees and is not known to be an aggressive snake, but will not hesitate to strike if harassed.

The fer-de-lance (aka terciopelo) likes moist environments, and occurs in most life zones located at low or middle elevations (up to 600 meters), excluding those with strong seasonal dry periods. These snakes have been described as excitable and unpredictable when disturbed. They can, and often will, move very quickly, usually opting to flee from danger, but are capable of suddenly reversing direction to vigorously defend themselves. In a review of bites from this species suffered by field biologists, Hardy (1994) referred to it as the "ultimate pit viper."

The jumping pit viper lives in moist forests, including tropical moist and wet rainforest, deciduous forest and lower cloud forest, as well as secondary forest. The common name alludes to the supposed ability these snakes have to launch themselves at an attacker during a strike, thereby bridging a distance that is equal to or greater than the length of the body. They are slow-moving and non-aggressive. However, when provoked all species will put on a rather dramatic open-mouthed threat display. These snakes may be active both during the day and at night.

The Olmecan pit viper lives principally in the Tuxtla Mountains. Its preferred habitat includes upper rainforest and cloud forest, including degraded forest and associated pastureland. It is not known to be quick-moving or aggressive.

The hog-nosed pit viper and Dunn’s hog-nosed pit viper occupy lowland rainforest and lower mountain wet forest. They have also been found in secondary forest. They are not known to be quick-moving or aggressive.

Rowley’s palm pit viper inhabits intermediate elevations cloud forest and moist ravines in pine-oak forest. It is found in primary forests and coffee plantations. They are not known to be quick moving or aggressive.

In trying to identify the most likely specie(s) of the poisonous serpents referred to in this event it must be noted that the Jaredite lands were not in the mountains but were in the low-lying flat lands, thus probably ruling out the pit vipers. The description given in Ether of the snakes indicate that they were fast moving and were apparently somewhat aggressive. That would indicate that the most likely candidate species is the fer-de-lance (aka terciopelo) (see figure 88). As the fer-de-lance is principally adapted to moist habitat, it would also be likely to migrate en masse looking for suitable habitat in the case of a drought.

Figure 88. Fer-de-lance (courtesy pariasprings.typepad.com, 2014)

The episode of snake migration described in Ether is not in the least far-fetched. Snakes often migrate en masse on a seasonal basis, and are known to migrate in search of water in the midst of drought. In 2007, a large migration of venomous brown snakes invaded the city and suburbs of Sydney, Darwin, and other areas of Australia that had been hit by the worst drought in 100 years, biting many people. The snakes were seeking water, and were much more aggressive than normal, although brown snakes are known to be an aggressive snake.

It has been suggested that the migration of snakes discussed in Ether was to follow a food source, namely the flocks (Tvedtnes, 1997); however, this does not appear to be consistent with the description that the fleeing animals that died were not eaten by the snakes, but were instead left for the inhabitants to collect and eat. It appears that the snakes were looking for water, and perhaps when water and moist habitat were located (perhaps a river?) they stopped.

The description in Ether about the snakes maintaining high population densities blocking or "hedging" passage of a particular area for a period of time might be explained by the lack or reduction of snake predators in conjunction with ample food supply, which may have occurred because of a significant removal of local bird predators as has been documented to occur as a result of volcanic eruption. There would be no competition from birds for the rodent or lizard food supply, and there would be no cap on the venomous snake population from direct predation by snake-eating birds.

This situation of ample food supply and lack of predation currently exists off the shore of Brazil, almost 93 miles away from downtown São Paulo, on an island called Ilha de Queimada Grande. The island is untouched by human developments because of snakes. Researchers estimate that on the island live between one and five snakes per square meter. The snakes live on the many migratory birds (enough to keep the snake density remarkably high) that use the island as a resting point. There are also no natural predators of the snakes on the island.

The snakes on Queimada Grande are a unique species of pit viper, the golden lancehead. The golden lanceheads that occupy the island grow to well over half a meter in length, and they possess a powerful fast-acting poison that melts the flesh around their bites. Golden lanceheads are so dangerous that, with the exception of some scientific outfits, the Brazilian Navy has expressly forbidden anyone from landing on the island.

Locals in the coastal towns near Queimada Grande recount grisly tales of death on the island. In one, a fisherman unwittingly wanders onto the island to pick bananas. Naturally, he is bitten. He manages to return to his boat, where he promptly succumbs to the snake's venom. He is found some time later on the boat deck in a great pool of blood. The other story is of the final lighthouse operator and his family. One night, a handful of snakes enter through a window and attack the man, his wife, and their three children. In a desperate attempt to escape, they flee towards their boat, but they are bitten by snakes on overhead branches.

There are many species of birds in the Jaredite/Olmec homeland area that prey on snakes and rodents including:

Gray-headed kite
Plumbeous kite
Crane Hawk
White Hawk
Great Black Hawk
Roadside Hawk
Barred Forest Falcon
Collared Forest Falcon
Laughing Falcon
Ornate Hawk Eagle
Black-and-White Hawk Eagle
Sharp-shinned Hawk
Bicolored Hawk
Common Black-Hawk
Broad-winged Hawk
Swallow-tailed Hawk
Great Horned Owl
Northern Pygmy Owl
Central American Pygmy Owl
Mottled Owl
Striped Owl
Northern Harrier

Great Blue Heron
Little Blue Heron
Black-Crown Night-Heron
Osprey
Wood Stork
Cattle Egret
Limpkin
Least Bittern
Yellow Crowned Night Heron

Elimination or decimation of these species would eliminate serious predators on snakes as well as removing competition for snake prey. There are also perhaps a hundred other species of birds in the Jaredite region, which, although not preying on snakes, prey on rodents or lizards, similar to the fer-de-lance. Elimination or depletion of these species would also allow population explosions of snakes utilizing rodents and lizards as a food source.

Notably, it is indicated in Ether that sometime later (approximately 400 years) the serpents were "destroyed," but does not say whether the methodology of the destruction was human or natural; perhaps it occurred naturally by the re-establishment of competing predator populations.

While any occurrence directly caused by volcanic activity is not enumerated in Ether for the Heth Event, the volcanic activity that occurred concurrent with the "dearth" may have been one of the causalities, and may also help to explain the poisonous serpent phenomenon.

Analysis of 1070 to 900 BC Jaredite Natural Disaster Event ("Shiblon Event")

The Shiblon Event does not mention any specific causality for this natural disaster, such as a drought, but states that there were "many famines and pestilences, insomuch that there was a great destruction, such an one as never had been known upon the face of the earth." Since there were volcanic eruptions occurring during this time period, it is plausible that these volcanic eruptions might be a primary cause of the Shiblon Event, as they are capable of precipitating drought, famine, and pestilence, and can cause great destruction.

Chapter 14
Evaluation of Other Book of Mormon Geographic Models

Regardless of location, based on geologic analysis, a basic screening for any proposed model must have:

- A volcano in the land northward, active and with eruptions during the 3rd Nephi time frame
- A regional fault system in the land northward with a presence or effect in the land southward capable of generating minimum intensities of Level VIII on the Mercalli intensity scale
- The city of Ammonihah must be in an area capable of producing an earthquake with a minimum intensity of Level VIII on the Mercalli intensity scale
- The land of Nephi must be located adjacent to a volcano active during the first century BC

Once the basic screening criteria are met, the actual locations of cities and geological occurrences would then need to be evaluated within the model.

The active volcano requirement essentially eliminates all Book of Mormon geologic models located in the central or eastern United States, Baja California, and any area in Central America south of Costa Rica from being viable models as a location for the Book of Mormon.

Other Isthmus Models

As has been discussed, the Sorenson model was used because it has extensive sets of detailed maps with meticulously documented references and sources, with multiple supporting books and documentation. It has specific locations identified where geologic events intersect the Book of Mormon record. There are other models of varying specificity in the Isthmus of Tehuantepec that differ from the Sorenson model. For the most part, the alternative models developed to map form differ from the Sorenson model in that the Usumacinta River is assumed to be the River Sidon as opposed to the Grijalva River. In addition, in varying degrees, the alternate models interpret the east sea to be on the east side of the Yucatan Peninsula with the locations of many of the Book of Mormon cities running along the coast starting in the Bay of Honduras and running northward, with other cities located in the south and central portion of the Yucatan Peninsula.

This inquiry is not designed to analyze all other models, in fact the principal purpose of the inquiry is to lay out the geologic framework so that others can utilize it to evaluate their own models if they choose. However, it would be useful to compare at least one of the academically developed models that relies on the Usumacinta River as the River Sidon and the east sea setting as the east side of the Yucatan Peninsula. The model proposed by V. Garth Norman, a recognized Mesoamerican archeologist, seemed an appropriately developed model to use as it provides a detailed map and sufficiently detailed discussion upon which to make a comparison. Kirk Magleby, another Book of Mormon geographic modeler has apparently endorsed the V. Garth Norman map (Magleby 2014), but has also developed different maps of his own, and though he does not appear to have formally published his maps in a printed form they are extant in the form of Google Earth overlay sketches as part of an internet blog site entitled bookofmormonresources.blogspot.com.

It is not necessary to write another book to make a comparison to the Norman model; in fact, many of the locations are essentially identical to the Sorenson model. As the geologic comparison is limited only to cities or areas where geologic events are described in the Book of Mormon to have taken place, the comparison can be thorough as well as being brief, and it will only be necessary to deal with locations that are not identical and also have geologic implications.

The following locations are essentially identical under the Norman and Sorenson models:
Land northward
City of Lehi-Nephi
City of Jerusalem

The following locations are entirely different:
City of Bountiful
City of Ammonihah
Great City of Moroni
Great City of Zarahemla
Great City of Moronihah

The land southward is not entirely different in the Norman model, but it does shift the main population centers to the Usumacinta river drainage and the south/center portion of the eastern Yucatan peninsula (the Sorenson model does not consider any of the eastern Yucatan peninsula). Locations from the Norman model map for geologic analysis are shown on figure 89.

Figure 89 - Locations Referenced from the V. Grant Norman Model

City of Bountiful and East Sea Cities under the Norman Model

As discussed in chapter 12, the main geologic criteria regarding the location of the city of Bountiful was that it be located in a zone that would have been expected to escape major earthquake damage but that it be close enough that observation of areas with major damage could be visually observed up to a year after the event. The location of the city of Bountiful under the Norman model is directly in the center of the Veracruz fault system. In this location, there would be little expectation that Bountiful would have been spared destruction, in fact, the opposite is the case in that the location would be expected to have maintained a maximum level of destruction.

The Norman model location for Bountiful is not a best fit location; the geologic evidence indicates that the city of Bountiful would not have been at this location.

City of Ammonihah under the Norman Model

As discussed in chapter 13, the requirements for the city of Ammonihah are that it be located in an area on or adjacent to faults sufficient to generate earthquakes of a magnitude high enough to cause the collapse of a prison (approximately Level VIII on the Mercalli scale). In addition, the underlying geology would need to be the type where fault movement could generate an earthquake boom. A map of the underlying geology for Ammonihah is shown in figure 90. The area is not seismically active. An analysis of the current earthquake data from the USGS Hazards program database shows that there have been no historical earthquakes measured within 100 miles of this location.

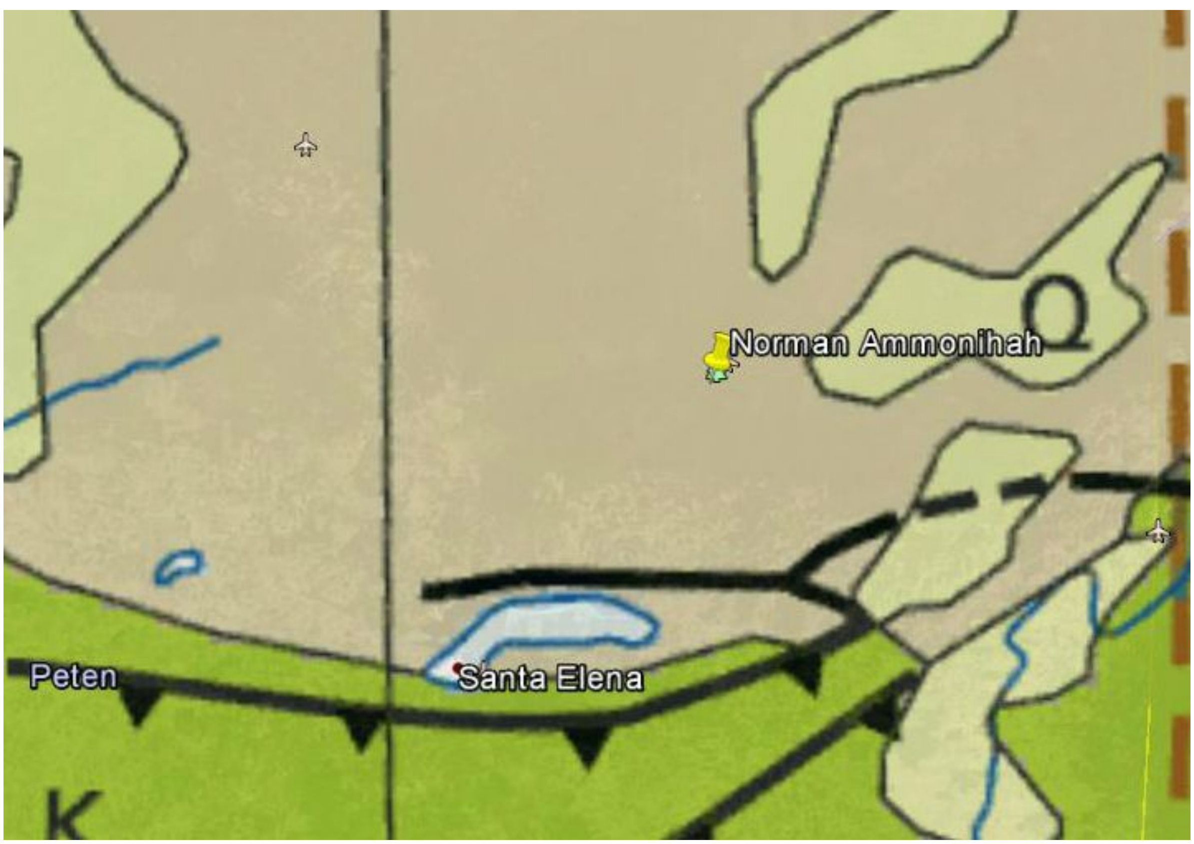


Figure 90. Geology of the Ammonihah area under the Norman model (USGS, 2005)

There is one minor combined normal/thrust fault located approximately 25 km to the south, but the fault is determined to be inactive as there has been no apparent offset of overlying quaternary deposits (within the last 2.6 million years). Liminological core studies in Lake Petén Itzá, Guatemala, which is located immediately adjacent to the fault, show no evidence of any earthquakes during Book of Mormon times or otherwise (Anselmetti et al., 2006).

The underlying geology is a sedimentary series of rocks, which is not the preferred environment for earthquake boom generation. In addition, earthquake booms exclusively occur in strike-slip fault regimes and the faults in this location are not strike-slip faults.

The location of the city of Ammonihah under the Norman model is not a "best fit" location. The geologic evidence would indicate that it is impossible that the city of Ammonihah was at this location.

Magleby (2011) does have a different location than Norman for the city of Ammonihah. Magleby's Ammonihah is located at approximately latitude 17° 14' 25" N longitude 90° 56' 00" W, 13 km west of the town of El Naranjo, Guatemala. Magleby's Ammonihah is adjacent to and just north east of the Reverse Faults Province, which experiences low level seismic activity from compressional reverse (thrust) faults (See chapter 3, figure 12).

Any location for Ammonihah must be in a seismic setting capable of generating a ground shaking of Level VIII on the Mercalli scale to account for the collapse of the prison structure as described in the Book of Mormon. In support of this location, Magleby has posted on the blogsite an earthquake hazard map created by the Global Seismic Hazard Assessment Program (GSHAP) (see figure 91). While the map is based on incomplete data in some areas of the Isthmus, it appears to reflect accurately the expected seismic activity in this area.

The map is a "10% in 50 years PGA" map type. The location Magleby has selected for Ammonihah falls in the 1.6 %g range on the map. PGA is an abbreviation for "peak ground acceleration," which is a method of measuring earthquake intensity. The Mercalli intensity scale uses personal reports and observations to measure earthquake intensity but PGA is measured by instruments, such as accelerographs, and PGA generally correlates well with the Mercalli scale. A 1.6 %g is equivalent to a very low Level IV intensity on the Mercalli scale. A complete comparison of the two scales is shown at the base of all of the Shakemaps shown in chapter 6 in figure 56. The "10% in 50 years" is a probability statement. It means that the location selected for Ammonihah has a probability of 10% of a Level IV earthquake occurring at least once within a period of 50 years. This is based on the scientific determination that every 500 years, one would expect one Level IV earthquake at this location. A Level IV earthquake is one that is:

> Felt indoors by many to all people, and outdoors by few people. Some awakened. Dishes, windows, and doors disturbed, and walls make cracking sounds. Chandeliers and indoor objects shake noticeably. The sensation is more like a heavy truck striking building. Standing automobiles rock noticeably. Dishes and windows rattle alarmingly. Damage none.

A Level VIII earthquake as described in the Book of Mormon in Ammonihah is roughly 20 times more powerful than a Level IV when utilizing comparative PGA measurements. The hazard map utilized by

Magleby shows, in fact, that the likelihood of a Level VIII earthquake at that location is extremely, extremely low.

As previously discussed, a useful determinant in evaluating any location for Ammonihah is the ability of the location to generate a supershear earthquake capable of creating an earthquake boom as described in the Book of Mormon. Supershear earthquakes occur almost exclusively on strike-slip faults. There are no strike-slip faults in the vicinity of Magleby's location for Ammonihah.

The location of the city of Ammonihah under the Magleby model, while faring better than the Norman model, still does not meet best fit requirements for Ammonihah. The geologic evidence would indicate that the city of Ammonihah was not at this location.

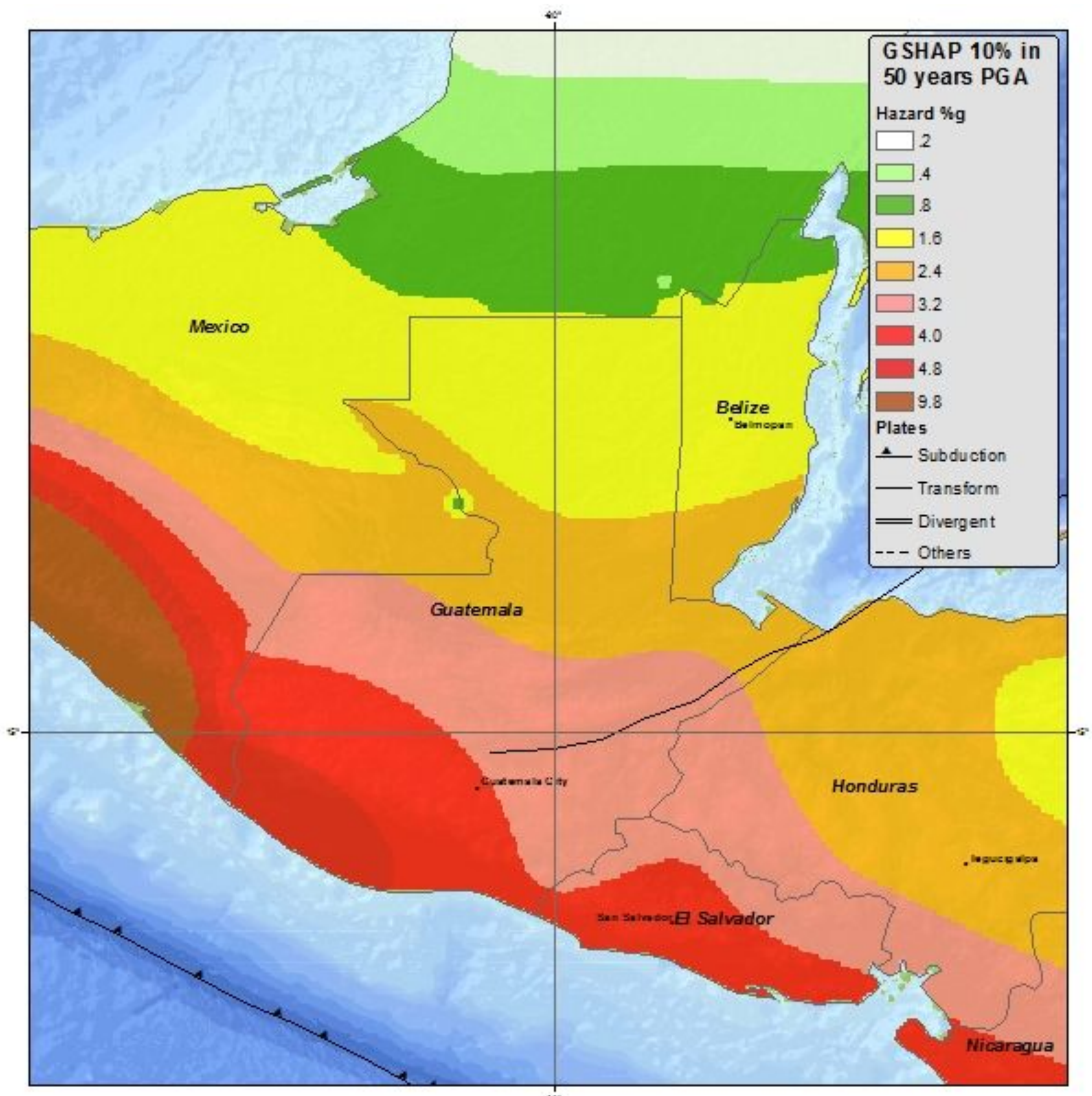


Figure 91. Earthquake hazard map from Magleby's blogsite (Magleby 2014)

City of Moroni under the Norman Model

The city of Moroni in the Norman model is located along the east sea. The location is within the Polochic/ Motagua fault system segment and could experience a significant earthquake and potential subsidence. However, this would require the occurrence of a large earthquake along this section in the land southward in addition to the earthquake occurring on the Veracruz fault system to the north.

Risk of a tsunami is also possible because of the offshore location of the fault system. Unlike the location of this city under the Sorenson model, there is no possibility of a volcano generated tsunami. Studies on soil conditions relative to liquefaction potential are not available as the scale of the map does not allow for a location specific analysis, so sinking caused by lateral spreading or liquefaction was not evaluated. The likelihood of a hurricane being a possible 3rd Nephi event are eliminated under the Norman model as discussed below.

The location of the city of Moroni under the Norman model currently meets the best fit standard pending a more specific location analysis.

City of Zarahemla under the Norman Model

The location of the city of Zarahemla under the Norman model is on the Usumacinta River at a location 7 km north of the town of Emiliana Zapata, at approximately latitude 17° 14’ 25” N longitude 90° 56’ 00” W. The most likely methods for Zarahemla to have taken fire and have had accelerated burning are lightening or earthquake induced ignition from existing human sources of fire in conjunction with high winds. A volcanic ignition does not seem likely as the Norman model location is far removed from any volcano.

An earthquake-assisted ignition (overturning candles or other such elements of fire) is plausible based on the intensity equations and intensity calculations discussed in chapter 10, indicating a Mercalli intensity of Level 4 to 5 because the city lies within 190 km of the Veracruz fault system.

The location of Zarahemla under the Sorenson model does sit closer to the Veracruz fault system than the Norman model, and the Sorenson location actually sits directly on the Polochic/ Motagua fault system, and so would have a greater probability of earthquake effect than the Norman model. Nevertheless, the location of Zarahemla in the Norman model is reasonably consistent with the geological conditions of the Book of Mormon.

City of Moronihah under the Norman Model

Norman has located the city of Moronihah at the extreme southern end of the land southward near a large group of volcanoes. Unfortunately, the scale of the map and explanations given on the map do not indicate which volcano is proximate to the location. As previously discussed in chapter 12, the possibilities for the destruction of Moronihah are a large landslide in a river valley within the Mercalli intensity level 8 zone of the regional earthquake, a mud volcano, or a volcanic debris avalanche. The Norman location of Moronihah is not in an oil and gas province, so a mud volcano is not a possibility.

The location is also too far removed from the Polochic/ Motagua fault system for a landslide triggered by an earthquake to be a possibility. The location requires that a second volcano eruption occur in addition to the volcano in the land northward, which provides less probability for the location under the best fit analysis. Presuming that one of the many volcanos in the area was active during the appropriate time period, then the location of Moronihah as shown in the Norman model is a geologic possibility.

The land southward under the Norman model

The Norman model of the land southward, differing from the Sorenson model, places the majority of the cities in the land southward in the Usumacinta River drainage and the south/central Yucatan Peninsula with a population concentration along the east coast of the Yucatan Peninsula. This expansion of the size of the land southward essentially eliminates the possibility of a hurricane being an element in the 3rd Nephi destruction involving the land southward; as discussed in chapter 7, the fastest forward speed ever measured for a hurricane is less than 70 miles per hour. It would not be possible for the hurricane to traverse even the land southward (let alone the land northward) on any hurricane path coming from the north or east within the 3 to 3.5 hour time limit, as the land southward under the Norman model is over 400 miles in width. As was previously mentioned, a hurricane is not an essential element to describe disaster events in 3rd Nephi, provided that the model locates cities and lands in places where a volcano and/or earthquake can account for the damage described.

Third Nephi requires that there was “thick darkness upon all the face of the land” with the only known phenomenon matching the description being distribution of ash from a volcanic eruption. Though the term “all the face of the land” does not necessarily mean that every square mile is contemplated, the description does imply that it is widespread over most of the face of the land. The size of the land southward under the Norman model necessitates the eruption of volcanoes in the land southward in order to accommodate the much larger area of the land southward. As discussed in chapter 8, a multiple volcano phenomenon is not unknown, but under the best fit analysis it is less probable. The descriptions given in 3rd Nephi indicate a volcano in the land northward, but no specific and unique volcanic damage of any sort (unlike specific cities in the land northward) is indicated in the land southward. If a significant eruption did occur in the land southward, it would need to be some distance from populated areas, as no cities were apparently buried by pyroclastic or surge flows.

While the Book of Mormon only provides a specific damage report for three cities in the land southward the Book of Mormon does state (3 Nephi 8:11) that “there was a great and terrible destruction in the land southward.” Under the Norman model, the bulk of the population is located beyond the reach of any volcano (except for windborne ash distribution). As has already been discussed, a hurricane is also not consistent with the Norman model, which leaves the only possibility for great and terrible destruction to be caused by an earthquake.

The Norman model positions significant population in the central or north part of the Yucatan peninsula, where there is virtually no possibility of damage from earthquake as this area is completely inactive seismically and considered the most stable seismic area in the entire Isthmus.

There have been virtually no historical earthquakes along the east margin of the Yucatan peninsula except on the very southern end where the Polochic/Motagua strike-slip fault system enters the Caribbean Sea. Nearly all of the cities on the eastern Yucatan are located significantly inland beyond the reach of an earthquake-generated tsunami from the Polochic/Motagua fault system. In any event, paleotempestology core studies have shown no evidence of a significant tsunami along the eastern Yucatan Peninsula (McCloskey, 2009).

In addition, the Norman model places much of the population along the Usumacinta River, a location in excess of 100 km from the center of the main strike-slip fault system in the land southward, and based on attenuation factors even the most catastrophic earthquake on the Polochic/Motagua strike-slip fault system would be at a Level VI intensity. A Level VI earthquake on the Mercalli scale can expect the following lower level of damage:

> Felt by everyone, outside or inside; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight to moderate to poorly designed buildings; all others receive none to slight damage.

Along the lower stretches of the Usumacinta drainage there are some areas of soils that could amplify and increase the intensity, but those areas are even further away from the main fault system at approximately 170 km. The Usumacinta drainage (see figure 12) would be located northeast of the Reverse Faults Province, running from southeast to the northwest. As is noted in the figure, the Reverse Faults Province recorded only minor seismic activity and would not be expected to have earthquakes reaching an elevated intensity level. There are deep subduction zone related earthquakes that do occur in the Usumacinta drainage (as well as within the Grijalva drainage that is central to the Sorenson model) but because of their depth they are significantly attenuated on the surface and do not typically generate extensive surface rupture.

When evaluating best fit, the land southward under the Norman model would only meet the requirement of “a great and terrible destruction” if an interpretation is made of the Book of Mormon text that includes only a lesser portion of the land southward. The Sorenson model for the land southward would be the best fit with regards to potential destruction of population centers both by earthquake or volcanic eruption.

Chapter 15
Conclusions

Since this is the first real effort to actually look at Book of Mormon geology with any type of specificity, and given the broad geographic area that needed to be covered, there is no doubt that whatever conclusions are reached in this work will be subject to future modification and refinement. As with all Mesoamerican inquiries related to the Book of Mormon, for certain areas additional data is needed in mapping, dating, and testing of Mesoamerican volcanic deposits, as well as in historical earthquake events and paleotempestology. The analysis and inquiry have been successful in providing significant new insights into the Book of Mormon as follows:

Geologic criteria established for the evaluation of all Book of Mormon geographic models

Certain basic criteria are established for the evaluation of any geologic model. The first criteria that must be met for any model is the inclusion of an active volcano and a regional earthquake in the land northward. Other levels of geologic criteria are then applied to each of the specific locations and areas proposed in each model. The Norman/Magleby models were evaluated where different from the Sorenson model. Some deficiencies were identified.

Sorenson model supported by known geological data

One of the principal goals of this endeavor was to compare the Sorenson model with the existing geology. The Sorenson Mesoamerican geographic model is accurately supported by the known geological data. In addition, analysis of these locations has provided further geologic explanation for scriptural events at some of these locations.

Areas defined for Book of Mormon cities whose location was previously considered unknown

The geological analysis has identified defined geographic areas for the following cities that were not specifically included in the Sorenson model:
City of Gadiandi
City of Gadiomnah
City of Jacob
City of Gimgimno
City of Gilgal
Great City of Jacob-Ugath
City of Laman
City of Josh
City of Gad
City of Kishcumen

Further, while not identifying defined geographical areas, the geological analysis has identified defined geographical settings for the following locations:
City of Onihah
City of Mocum

Reasonable scientific explanations given for all physical events referenced in the 3rd Nephi catastrophe and all prophetic descriptions of that event

The variety of Book of Mormon events and descriptions ranging from "tumultuous noises" to "great mountain" have *all* found a reasonable and plausible explanation in the geology and meteorology within the Isthmus of Tehuantepec.

Locations defined and established for geological events in the 3rd Nephi catastrophe

Another goal of the endeavor was to analyze what the Book of Mormon itself actually says and apply it to the known geology of the Isthmus of Tehuantepec, independent of any of the geographic models, and determine if any definitive results can be derived with regards to Book of Mormon events. Although scientists are reticent to use the word 'proven,' there are certain statements that can be made that are very close to the 'proven' standard.

1. A volcanic eruption occurred as part of the 3rd Nephi destruction
2. A volcanic eruption alone cannot account for all of the destruction in 3rd Nephi; the destruction necessarily involved a regional earthquake
3. Based on current data, a regional earthquake and one volcano and their after-effects can account for all of the destruction in 3rd Nephi, with the exception of the city of Jerusalem, which appears to be a local event
4. The primary regional earthquake occurred on the Veracruz fault system
5. The primary volcano involved is indicated to be the San Martín volcano based on its position in the Isthmus and on the Veracruz fault system, and the eruption need not have exceeded a 4 on the VEI explosivity scale.

As has hopefully been sufficiently explained, determining that a single volcano and a single fault system can account for all the destructive events in the 3rd Nephi does not mean that there were no other volcanos active or that were no other fault systems activated—there very well could have been.

Plausible locations and explanations of events framed and prioritized

As there are many locations and events where data was lacking (rendering an approach to a 'proven' standard unattainable) it was nevertheless possible to narrow the scope, frame, and establish probabilities using the "best fit" criteria for various geological events and occurrences. These inquiries should be a valuable framework to start from as additional data becomes available.

Finally, while not a scientific goal, it is hoped that this work may trigger interest by other geologists and scientists to direct their resources and expertise towards geologic or other studies that may shed further light on the Mesoamerican events that took place as referenced in the Book of Mormon.

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Since the initial publication of the Book of Mormon, attempts have been made to place it in its geographical setting. Various geographical models are being debated. In a book that is the first of its kind, Jerry Grover, a professional civil engineer and geologist, utilizes geologic and geophysical analysis with clues from the Book of Mormon itself to provide an eye-opening placement of the Book of Mormon in its geologic setting. The book includes extensive details and a professional academic technical analysis of volcanoes, fault systems, meteorology, and unlike many approaches that cherry pick conveniently to fit preconceived ideas, the author takes on and explains and documents all Book of Mormon references to geology and meteorology. The author's approach is meticulous and scientific. This book is a landmark event in Book of Mormon studies and is a book that must be read by every serious student of the Book of Mormon. The author is dedicating all proceeds from the book to additional scientific geologic and engineering studies to cast further light on the ancient setting of the Book of Mormon.