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The Iquique earthquake

May 9, 1877

and the caused by the same

Earthquake flood in the Great Ocean.

from

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1. *Removal of 'Br.' And 'L.', abbreviations for Latitude (Breitengrad) and Longitude (Längengrad)*
2. *Correction of abbreviation 'O' for Oste, translated in East 'E'*
3. *Correction of abbreviation 'St.' for Stunde, translated in hour 'hr'*
4. *Depth unit 'Faden' is translated in 'Fathoms', but 1 Faden = 1.90 meter and 1 Fathom = 1.83 meter*

nb: as a general precaution, because of translation hazards, for exact figures systematically refer to the transcript rather than to the translation.

The earthquake which struck the west coast of South America in a devastating manner on May 9, 1877, and in the wake of which a great earthquake tide occurred which moved the entire Great Ocean, has already been discussed in an earlier paper[1]. A treatment of this great natural event appeared therefore of interest, as it was the second one, about which relatively exact and complete notes and observations were available, according to which, one could gain a reasonably safe reference about the questions to be connected here.

The questions, which are of special importance here, are, besides an exact determination of the earthquake phenomenon itself, especially the discussion of the tide, which nature caused by that great "experiment"; after determination of these data, finally a calculation can be made about the average depths of the parts of the ocean passed by the waves.

Predictably, there was a great agreement with the results which F. v. Hochstetter had drawn from the earlier phenomenon of August 13, 1868. [2]) This mentioned event affected exactly the same places with the same intensity. Also at that time the violent earthquake, which had its center very near to the present one, was accompanied by a great flood movement in the Great Ocean. The similarity of both events was also immediately very striking to all concerned and in most reports there is a comparison with the event of 1868, or at least a reference to it.

The calculations of the average depths of the Great Ocean, which in general also yielded similar results as those of v. Hochstetter, could be compared with an overview of the latest depth measurements made in this ocean by the expeditions of the "Tuscarora", the "Challenger" and the "Gazelle" (by A. Petermann[3]). In general, the values found by calculation correspond to the data of the map, in some cases there are deviations, which can be easily compensated by a proper correction of the map.

The data, which I published at the mentioned places so far, were for various reasons partly incomplete, partly not very reliable. They have now been completed or confirmed by numerous reports, so that I consider it appropriate to compile all the material at my disposal in this place[4] and to discuss the mentioned questions again on the basis of it.

The most important and valuable material has been provided to me by the official reports which, at the request of Professor v. Seebach in Göttingen and through the mediation of the Royal Prussian Ministry of Spiritual, Educational and Medical Affairs, the Imperial German Foreign Office has collected with the most grateful willingness and liberality. I take this opportunity to publicly express my most sincere thanks to the High Imperial German Foreign Office and a High Royal Prussian Ministry of Spiritual, Educational and Medical Affairs. Affairs publicly express my most humble thanks for the liberal support. In the same way, I cannot refrain from expressing my most sincere thanks to the Imperial German Mission at Santiago, the Imperial German Minister Resident Offices at Lima and Bogota, as well as all the Imperial German Consulates, which with most grateful willingness and interest not only filled out the sent questionnaires, but also collected and made available further important notes.

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[1]) E. Geinitz, das Erdbeben von Iquique etc., in Göttinger gelehrten Nachrichten 1877, p. 558, and Petermann's Geograph. Mittheilungen 1877, p. 454

[2]) Ueber das Erdbeben in Peru am 13. August 1868 und die dadurch veranlassten Fluthwellen im Pacifischen Ocean; Sitzungsber. D.K. Akad. D. Wissensch. Wien. 58. vol. 2 Abth. 1868. - Further: Die Erdbebenfluth im Pacifischen Ocean vom 13. bis 16. August 1868 und die mittleren Tiefen dieses Oceans; ibid, and vol. 60. 1869. - Further in: Geograph. Mittheil. 1869. p. 222, plate 12.

[3]) Die Bodengestaltung des Grossen Oceans, mit Karte : Geogr. Mitth. 1877, p. 125, pl. 7.

[4]) Unfortunately, the publication of this treatise has been delayed until the present time due to various circumstances.

By sending notes, etc., I was also greatly assisted by Messrs. C. Anwandter, Valdivia, F. Arnemann, Dresden, Professor Buchenau, Bremen, P. F. Enrich, S. J., Puerto Montt, W. Frick, Valdivia, A. Gildemeister, Bremen, C. Godeffroy, Hamburg, Hofrath v. Hochstetter, Vienna, Consul Moësta, Dresden, H. Mohr, Bremen, Professor E. Naumann, Yeddo, Consul Ochsenius, Marburg, H. Reck, Hannover, H. C. Russell, Sydney, Professor v. Seebach, Göttingen, Dr. A. Stübel, Dresden, Consul A. Weis, Dresden, u. A.

A special scientific commission was appointed by the government of the Republic of Chile to collect notes. The Imperial German Minister-Residentur Lima had the questionnaires translated into Spanish and distributed to the port offices so that the best possible reports could be obtained.

The "Weserzeitung", the Valparaiso "Deutsche Nachrichten", as well as "El Ferrocarril" in Santiago included the questionnaire in their columns for further distribution.

I am especially indebted to Professor Dr. Freiherm K. v. Seebach in Göttingen, through whose kind mediation I came into possession of the above-mentioned official reports and who supported me not only in collecting notes, but also by communicating the Spanish reports in the strongest possible way.

The questionnaires, which, as mentioned above, were distributed by the Imperial German Foreign Office, were written in the following form:

"For a scientific investigation of the recent earthquake and seaquake of May 9 and 10 of this year, which in turn would allow the calculation of the mean depth of the shaken part of the South Seas, it is desirable and necessary to answer the following questions from as large a number of affected places as possible:

1. place of observation:
2. at which time the earth tremors at the west coast of America took place, which degree of reliability or accuracy have these time data (sextant observations? time ball? average local time?):
3. from which directions did the shocks seem to come?
4. at what time (possibly again with indication of the degree of accuracy) did the first, extraordinary flood movement of the South Seas occur?
5) Did this flood movement start with an over- (out-) stepping or with a running back of the South Sea?
6. how many such fluctuations of the sea have taken place and in what intermediate periods?
7) What size, height above mean high water mark did they reach, and what was the largest?
If self-registering tide gauges are available, a copy of the registered extraordinary tide movement would be desirable.
9. special remarks on any accompanying phenomena and extraordinary effects.

Mineralogical - Paleontological Institute of the Royal Prussian University of Göttingen.
Professor Dr. K. v. Seebach, First Director.
Dr. E. Geinitz, assistant of the geological department.
"

The tidal movement of the sea caused by the Iquique earthquake spread over the entire surface of the Great Ocean. It was observed along the west coast of America on the extension of 80 degrees of latitude (from 42°S to 38°N), furthermore on the various islands of the South Seas up to the east coasts of Australia and Japan.

In the following, the news are compiled, which I have received about the earthquake and flood phenomenon from the different points in the Great Ocean. In spite of the relatively sparse number of the notes, they already provide sufficient valuable material to draw general conclusions from the great natural event, which are valuable in several directions. The individual reports were reproduced partly quite detailed, because with the often

extremely scanty and deficient observations also the seemingly insignificant detail remarks can often be of special value and also give information about the degree of the reliability of the observation concerned, partly, however, also many reports had to be discharged of their for the present purposes unessential additions.

Hopefully, the following treatment contributes something to arouse the interest of the numerous observers of such phenomena not only in them, but also to indicate at the same time the methods and principles on which it depends mainly for an appropriate and useful observation of the events.

We let follow first the reports, which are available from the American coast, and start thereby from the point, which turned out by the investigation as the Centrum (or the place situated first to the Centrum), from the Peruvian city Iquique. From there, we will first follow the places along the coast to the south, and then we will collect the news from the points located north of Iquique.

At **Iquique** (20° 12½' S., 70° 14½' W. Greenw.)[5]) the earthquake occurred, according to the Consulate report, "at 8 hr. 20 min. in the evening of May 9, mean local time, according to fairly generally ascertained observations. The initial motion appeared to come from the east, but as the earthquake progressed the direction changed continually and the motion was oscillatory at times, trepidatory at others. The first "surge" of the sea occurred at 8:50 min p.m., about 1/2 hour after the earthquake. The movement was gentle, but the return of the water was significantly faster. One wants to have noticed a backflow of the sea before its first swelling, certain is not determined, as also with the darkness difficult, over it. The second sea outburst, already more violent than the first, took place at 9 hr., followed by 3 more in longer or shorter pauses according to some, 5 according to others; the last one, at 1 hr at night, after another violent earth tremor, was the worst. Which fluctuation of the lake was the greatest has not yet been fully determined, but it is fairly certain that it was the last. The height above mean water was almost exactly 16 feet. In the hinterland, which lies 3400-3800 feet above sea level, at a distance of about 35 English miles from the same, bubble-like swelling of the ground - it is the same on which the saltpetre mines lie - has been noticed during the night and the following day. For example, in two saltpetre factories, only about 500 paces apart, has been heavy in one and light in the other. - The sea had shown significant and unprecedented changes in currents several months before the earthquake and as late as December 1877, being very slightly agitated and its level in some places close to 2 feet higher than before May 9."

Iquique Port Authority reports that at 8 hr. 20 min. p.m. [6]) (according to most clocks) a noise with little movement was noticed for a few seconds, then a strong movement began in the direction from E. to W., ending with short and strong shocks in the perpendicular direction. The first wave, or rather the rising of the water, took place 5 minutes after the shock (at half tide). The bottom of the sea seems to have sunk after that, in that many cliffs in the harbor are now no longer visible even at low tide.

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[5]) The geographic locations given below are partly taken from the work of A. G. Findlay, A Directory for the Navigation of the Pacific Ocean, London 1851, partly from the information on the respective official submissions, partly from more detailed maps.

[6]) As is well known, the abbreviation p. m. means the time from 12 noon to 12 midnight, post meridiem, and a. m., ante meridiem, the time before 12 noon.

Of the numerous reports which bring news about the catastrophe in Iquique, the following, already communicated earlier[7], are mostly mentioned. The "South Pacific Times", Callao, of May 10, reports: "About 8 ¼ o'clock last night (May 9) a faint rolling sound, accompanied by a slow movement of the earth, announced the approach of the terrible earthquake and the terrible oscillations from NW. to SE. foretold the catastrophe which followed. These movements lasted more than 3 minutes, and besides the rolling sound, the clouds of dust raised by the earthquake, the screaming of women and children and a general flight of the population to the hills with the shouts: the sea, the sea! The prolonged oscillation disturbed the balance of the sea, which soon flooded higher terrains, destroying and carrying away the workers' quarter of the city. The loss of property can be estimated at 2½ million soles[8]. Several ships were damaged. "The small port of Molle, south of the port of Iquique, was almost completely destroyed.

According to another report in the same newspaper, the earthquake occurred at 8 o'clock 20 min. p. m. and the sea rose 20 minutes afterward; the same had broken into the city eight times during the night; its greatest height was 20 feet. A communication from Dr. Watson to the "S. Pac. Times" says: "An earthquake, the most violent ever observed in Iquique, occurred at 8 o'clock 22 min. last night (May 9); its duration was the longest known in Peru, lasting without any interruption 4 minutes and 20 seconds, and was terribly violent, so that it was impossible to stand without support. Two very violent flood waves followed afterwards and made of the lower parts of the city a complete heap of rubble. To add to the misfortune, a fire broke out, but was soon extinguished, so that the destruction of life and property was limited to the fury of the ocean. During the night and today the blows continue, in a very mild form... The steamer "Griminoza" and a schooner lie high in the dry on the island." - Another news gives the movement as going from SE. to NW. - According to the "Diario oficial de la República de Chile," Santiago, No. 62, 30 lives were lost in Iquique. The water rose 6 to 10 feet on the walls of the Duana.

A private correspondence from Iquique to Mr. Gildemeister in Bremen of May 10 reports the following details: "At 8:25 last night we were surprised by the first quiet blast, which became increasingly stronger and noisier, soon oscillando, soon trepidando, lasting about 5 minutes and making everything tremble. One could hardly stand and walk. Then the force died down a bit, but the terrible noise continued. In the midst of this confusion, fire broke out from falling lamps, and the fire sprinklers began to work, when suddenly the call rang out: El Mar se retire ! Everyone ran for cover as the water roared in again, devouring everything in a furious whirl, overflowing our unfortunate city four or five times, usually from the north. We do not need to describe to you the scenes in the midst of the continuing earthquake and thunder... We camped in the pampas until 3 o'clock in the morning and then returned to our home, while at that very moment the earth was still shaking and rumbling."

A report from the Saltpetre Officer **San Pedro**, 40-50 kilometers southeast of Iquique and located at an altitude of 4 - 5000 feet, reports: "The catastrophe occurred on May 9, 8 1/2 o'clock in the evening and began with two vertical jolts, which were followed by a horizontal wave-like movement, which gradually increased to a strong shaking, accompanied by a strong roar, which had its cause partly in the earthquake itself, partly in the collapse of buildings. This first strong shaking lasted 6 minutes and caused the destruction that occurred. During the whole night many more or less violent shocks followed, which made all moving parts of the machine sound, but none of them resulted in a collapse. Fortunately, no one was

[7]) op. cit. p. 454
[8]) 1 Sol = 4 Mark 5 Pf.

killed, only some contusions by falling debris occurred, the slow increase of the phenomenon allowed time to escape."

The city of **Tarapacà**, located in the interior of the country, 23 miles from Iquique, as well as the villages of **Pica**, **Matilla**, **Canchones** were more or less destroyed by the earthquake.

Now let's follow the news we have about the phenomenon from the west coast towns south of Iquique.

Pabellon de Pica, located 0° 45' south of Iquique, has also suffered extraordinarily and, at the same time, lies within the closest shaking area, along with the sites located in the immediate vicinity to the north and south of Iquique.

The South Pacific Times reports that Pabellon de Pica was completely destroyed; 5 ships sank and 27 were so badly damaged that they could not leave the harbor, more than 200 lives were lost; "the movement of the sea caused by the earthquake was similar in the harbors along the coast from Callao (Peru) to Coquimbo (Chile), although of different intensity, most marked and violent at Pabellon de Pica, which may be called the center of the disturbance. "According to this news, the earthquake is said to have occurred at 8 o'clock p. m. and to have lasted 5 minutes, during which time more than a dozen fires broke out, caused by overturned lamps. At 8 o'clock 25 min. the sea broke.

The report of the governor of Pabellon de Pica to Lima says: "At 8:15 in the evening of May 9, a powerful earthquake began along the entire coast, which lasted 5 or 6 minutes, gradually increasing in intensity and ending with the sudden outbreak of a conflagration, which was then extinguished by the sea, which broke six times and caused great damage. In Pabellon, 33 workers were buried by a landslide.

The report of the port office at **Chanabaya** (Chanavaya), (21° S.) near Pabellon de Pica, to the Imperial Mission at Lima gives the time of the first push as 8 o'clock 20 min. p.m. (ordinary time). The surge had come from the coast. The first wave came 20 minutes after the first shock. The movement of the sea began with a sinking. Three waves at intervals of 8-10 minutes; the second wave was the highest, rising to 35 feet; the tide was 4 feet above ordinary. (Three or four days before May 9, a strong earth tremor was noticed.) - More than 3500 people helpless.

According to the "Deber" No. 550, the terrible earthquake occurred in Chanabaya at 8:30 a.m.; a conflagration broke out and the sea overflowed. Throughout the night, the quake continued at intervals of a few seconds. Still until May 11, the earthquakes repeated themselves from 5 to 5 minutes. Several fissures, some 15 meters deep, appeared in the earth. According to the "South Pac. Times", five waves occurred over Chanabaya in the period from 8:25 to 10:10.

Noteworthy for the way of the flood movement of the ocean within the strongest shaking area is the note of the "Diario oficial", according to which Chanabaya was completely "lifted up" by the water.

The same phenomenon occurred at **Punta de Lobos** (21 5½' S.), where the houses were completely uplifted by the sea. According to a correspondent of the "South Pac. Times," the earthquake was felt here at 8:30 p.m., and was followed by others of lesser magnitude throughout the night. Immediately after the shock, the sea began to recede and returned in less than 10 minutes as a tidal wave, washing away everything at a height of at least 35 feet above sea level.

Quite consistent with this report, the port report from Punta de Lobos states that the first surge was felt at 8:20 local mean time; all surges were from SE to NW. The first wave appeared at 8:30 min p.m., i.e., 10 minutes after the surge. The movement began with the sinking of the sea. Two waves, of which the second was the larger, at intervals of 30 minutes ; the first rose 20 English feet, the second 35 feet above the mean level.

The port report of **Guanillos-Guanera** del Peru, 21° 10' S., 70° 13' W., states that here the shock was noted about 8:15 min. p. m. (mean local time) of May 9 was noted coming from the east, from the interior plains.

About 15 minutes after the first shock, at 8:30 p.m., there was a gradual recession of the sea, followed by its emergence, rising insignificantly above its level. The outburst occurred in a noticeable manner three times, at intervals of about 1/2 hour. The first wave rose 30 feet above the usual level, the other two slightly less.

Here, too, the houses were lifted up by the sea, according to the "Diario oficial". - Four ships sank, 13 were damaged,

several people were killed.

Here, as in Punta de Lobos and Chanabaya, the movement of the sea is said to have begun with a sinking of the water.

In **Tocopilla**, Bolivia (22° S.), great devastation took place. According to F. Palma ("Diario oficial") the earthquake occurred at 8½ o'clock in the evening of May 9, according to others at 8 o'clock 5 min. Immediately after the violent earthquake the sea came out and devastated the place. According to the report of the "Eten" (see below), it rose 15 minutes after the earthquake.

More than half of **Cobija** (22° 34' S., 70° 21' W.) was destroyed. The very violent earth tremor occurred 8 ½ o'clock in the evening; it damaged or devastated almost all houses. After that the sea came out and caused great destruction. According to the report of the "Eten" (see below), the sea rose by 30 feet, 8 minutes after the earthquake.

Caleta suffered the surge at 8:20 p.m., and 20 minutes later the tide rose 60 feet,

Mejillones de Bolivia (23° 6½' S., 70° 35' W.) was also almost completely destroyed. The earth tremor occurred at 8:15 p.m. and is said to have lasted 7 minutes. The movement of the earth is first described as undulating and slow, which accelerated after the first minute, and finally the earth maintained a strong rotating motion. "Those who tried to go south turned to the east." After two minutes, the strong motion decreased again. The sea penetrated ½ hour after the movement without being noticed before. The vertical height of the wave was 35 feet. After this first overrun, the sea retreated about 2 cuadras; ¼ hour after the first overrun, the second powerful emergence occurred at a dizzying speed, in which the wave reached 70 feet or more in height and caused great damage. About ¾ hours later, the third spill took place. - The shocks were also felt on the sea.

In **Caracoles**, the earthquake is said to have lasted 7 - 8 minutes, but the place suffered little.

According to a private communication from Dir. C. Baur from Caracoles, the violent and long-lasting earthquake took place here at 8:27 p.m. on May 9, which overturned all furnaces, etc. Mr. Baur was able to observe the duration and direction very precisely. The strong shaking lasted 2 min. 40 sec.: afterwards about 8 minutes of weaker shaking, but also throughout the night it shook with short interruptions and even for 15 days no day passed without one or more earthquakes. The direction in Caracoles was NW. - SE. and must have been the main source of the movement only a few leguas from the coast in the sea. The earthquake wave played Antofagasta only little, since the Morro Moreno is just in this direction. Calama and Chiuchiu (located in the interior of the country) are said to be almost completely destroyed by the earthquake and Chacanche also suffered a lot.

Antofagasta, Bolivia: 23° 40' S., 70° 30' W. "Diario oficial" No. 65: Wednesday, May 9, in the evening of 8½ o'clock, a prolonged earth tremor was felt, with vibrations so strong that one had to hold on to be able to remain on one's feet. Its duration was not more than 5 minutes. Since the houses of this place are built of wood, no damage was done. Unfortunately, however, the sea soon came out, penetrated the quarters three times and destroyed some houses, transported others from one place to another, some over a whole quarter, and caused great damage in the magazines. The earthquake repeated itself in soon shorter, soon longer intervals.

"Deber" No. 548: At 8:32 p.m. one of the strongest earthquakes observed so far occurred, of unusual intensity on this coast. The motion is described as wave-like, as on water. The earthquake lasted with increasing

force 3 minutes, according to others 5. Until 11 o'clock at night continued movement of the ground and the sea; at 11 o'clock violent noise of the sea. The movement went from N. to S. Within 36 hours more than 80 earth tremors took place. Antofagasta suffered comparatively not very much.

According to another report, the earthquake began at 8:35 p.m., first gradually, then increasing to the point that the buildings shook back and forth like wood. The earthquake was not preceded by any underground noise; the movement was a sudden one, it seemed to go from N. to S. The earthquake may have lasted 2½ to 3 minutes at its greatest intensity. The sea was motionless, although usually very agitated, until the big wave came. From time to time it still trembled, sometimes weaker, sometimes stronger, and on Thursday evening the population had to flee again to the mountains, but a new outburst of the sea did not take place.

The consular report from Antofagasta now reports: The main blast was on May 9 in the evening 8½ o'clock and the blasts continued almost uninterruptedly all night and the following days. They came from ENE, with sharp undulating motion. The first tidal movement of the sea occurred about 10 minutes after the first surge, which lasted about 3½ minutes, and began with strong receding seas. From the beginning until 12 o'clock at night, Mr. Bischoff noticed four strong fluctuations of the sea, but smaller ones lasted throughout the night and the following two days in intervals of 40 - 80 minutes. The fourth, largest wave reached a height of two meters above the high water mark or 2½ meters above the mean water mark. During the phenomenon there were heavily cloudy skies and unusually dark evening, with very muggy air. An underground noise has been noticed.

At this point, the following two reports should be repeated:

Capt. G. Massey reports in the "South Pac. Times" of May 21: "While the steamer "John Elder" was proceeding north from Valparaiso to Callao, on Wednesday the 9th of this month in the evening at 8 o'clock 20 min. in latitude 23° 43' S. and 70° 47' W., when about 23 miles west of Antofagasta, while the sea was as calm as a pond, suddenly, without the slightest warning, everyone on board was violently alarmed by a sudden, very violent shock and vibration, which was felt in the ship from fore to aft and which, as we learned afterwards, was caused by an earthquake. Soundings found no cause until 20 fathoms. Although the ship was going at full speed, she was stopped by the shock for a full 4 to 5 minutes..." Captain Coathupe of the "Eten" felt ("South Pac. Times," May 21) in his steamer, anchored at Antofagasta, at 8 o'clock 15 min. p. m., a sharp earth shock which shook the ship for 2 minutes, so that the steamer weighed anchor and proceeded to Mejillones de Bolivia; on the way he felt several shocks during the night... At Caléta he heard that about 8 o'clock 30 min. p.m. the ships in the harbor were suddenly lifted 45 degrees at the star; about 20 minutes after the shock the sea broke and rose 60 feet.

Caldéra, Atacama Province, Chile, 27° 4' S., 70° 52' W., port north of Copiapó:

In addition to the earlier news, we have a precise report of the German Consul in Caldéra, Mr. J. Scheffler, which was found to be reliable by comparison with the observations of the harbor captain of the lighthouse and other sources. This gentleman has also graciously enclosed two official excerpts from the meteorological notes of the lighthouse there (27° 3' 15" S., 70° 53' E" W.).

The older information (op. cit. p. 457) is briefly repeated here:

Valparaiso "German News": The phenomena in the last earthquake were very insignificant here compared to the north. On the 9th of May in the evening 8 o'clock 25 min. the earth began to tremble, at first gradually, then with increased violence, until the oscillations reached their peak after about 1 ½ minutes. The oscillations went from north to south, but were very little dangerous in our area. Their duration was 3 to 3 ½ minutes. (The previously serene sky suddenly became covered with clouds.) About 11 o'clock at night the sea suddenly began to retreat silently to a distance of about 200 feet, whereupon it again filled silently quite gradually, without any

wave action, until it exceeded the highest tide level by about 5 feet taken vertically. This movement continued in its full strength until the next day; eddies also formed again. - The steamer "Ayacucho", which was sailing south from Caldéra, felt the earthquake very strongly.

The consulate report states: According to the clock of the lighthouse the earthquake occurred at 8 o'clock 20 min., according to local railroad time at 8 o'clock 26 min. (The former clock is regulated by observations of the sunrise and sunset from time to time, the latter sometimes by sextant or also sundial observations of a naval officer). The impacts came from north to south. About 9 p.m. (May 9), the sea began to retreat, and the first tidal wave occurred at 9:30 min, about an hour after the earthquake. The tide movement started with a receding, but slowly descending, tide. The ebb and flood alternated at very irregular intervals, often every 5, then 10, 15, and 20 minutes; especially frequently at the beginning and the following day. The greatest height was reached by about the third tidal wave at 1:5 a.m. (railroad time) on the morning of May 10, which rose 7 feet above the mean-water mark, 4 feet above the high-water mark, i.e., 14 feet from the lowest level, while the usual difference between low and high tide is only 6 feet. A tidal wave reached about the same height on Friday, May 11, at 7 a.m. and 4 p.m.; these waves, however, were less violent, rising more slowly. - The duration of the earthquake, which was strongly vibrating and undulating and caused hanging lamps to oscillate from north to south, was 3 minutes 20 seconds in Caldéra, according to Mr. Scheffler's own exact observation, which agrees perfectly with that of the harbor captain and the board of the lighthouse.

From **Copiapo** (27° 20' S., 71° 2' W.) telegrams to Santiago ("Diario oficial" No. 59, 65) report: During the night of May 9 strong earthquake, the movement is said to have been from N. to W., according to others from E. to W. No accident. The first movement of the earth occurred at 8 o'clock 20 min. p. m., it was followed by numerous movements throughout the night; up to 11 ½ o'clock in the morning of May 10, tremors were still felt from time to time. - A strong tremor was felt in Chañarcillo and other places in the valley. The earth remained in continuous motion from 8:30 p.m. until the evening of May 10; the earthquakes were without noise and of varying magnitude and duration (up to over 4 minutes).

South of Copiapo, in **Carrizal alto** and **Carrizal bajo**, the earthquake occurred at 8:30 min. p.m. and had the direction from north to south. At about 10 o'clock, the sea retreated and overtopped it. The subdelegate of Carrizal bajo reported that at 10 ½ p.m. it was noticed how the sea slowly retreated and 10 minutes later filled and its level rose to 4 feet above the highest tide mark. The rising and falling motion of the sea repeated for more than 3 hours, damaging several ships.

From **Vallenar** it is reported to the "Diario oficial" No. 65 that here on the 9th in the evening 8 o'clock 10 min. a strong wave-like earth shock was noticed, which lasted 2 minutes. No sound preceded; the movement appeared horizontal.

In **Freirina**, the earthquake lasting 3 to 4 minutes occurred at 8 ¼ o'clock. Until the 10th, four more shorter tremors occurred.

About the devastation in **Chañaral** (29° 2' S., 71° 34' W.) the "Deutsche Nachrichten" reports the following: "After a strong earth tremor on May 9 in the evening of 8 ¾ o'clock, which lasted 2 minutes, the sea receded about 2 cuadras, which was the signal for the population of the lower lying parts of the city to a general flight to the heights. 1 ¾ hours later the sea came back and flooded all buildings from the Crucero de Magallanes to the railroad station. After this first flooding, fire broke out in the buildings of the Compañia de Carrizalillo, turning them into a smoking ruin in barely two hours. Hardly had it been possible to control the flames and to set limits to the fire, so that the central point of the commercial traffic was no longer threatened, when a second, much more powerful wave rolled in, which, however, completely smothered the fire, but also completely submerged all the houses for 5 cuadras...".

We let follow on plate 1 the copy of a map of Chañaral, which is taken from the supplement to No. 70 of the "Diario oficial de la Republica de Chile", May 25, 1877, in order to give a picture of the terrible destruction of these parts of the city.

The occurrence of the earthquake in Chañaral is reported in the "Diario oficial" No. 58, from 8 o'clock 40 min. p.m.; at the same time it is said that after more than 2 hours a strong wave movement of the sea occurred and that the sea had leaked 50 to 100 meters above the highest tide mark. The second even bigger and more devastating wave was twice as big; its direction was from S. to N. - A correspondent of the "D. Nachr." reports the time of the earthquake at 8 o'clock 25 min. - According to a news of the "Mercurio del Vapor", No. 542, the sea in Chañaral already came out rushing at 9 ¼ o'clock and gained more and more terrain and at 10 ½ to 11 o'clock it broke into the city.

A letter from Mr. C. Waltenrath from Chañaral to the editorial staff of the "Weserzeitung" reports the following in response to the inquiries kindly distributed by the said newspaper: "The earthquake occurred at about 8 ½ o'clock in the evening, it was not an exceptionally strong one, but so strong that, for example, the lamps on the tables began to jump and so that they did not fall, one had to hold them. It lasted probably one minute and 45 seconds, but intermittently followed by minor tremors all night. - The exit of the sea occurred about 2 hours later, but a little before that a stronger movement of the waves was noticeable. - The wave motion began with (varying degrees of) sea run-off. - Here the sea came out three times. The first time it might have been 50 meters, retreated and came again, but did not emerge again. About 11 ½ o'clock it retreated without the slightest noise at least 200 meters and came back with the most terrible noise. The third and last discharge was 2 hours later and the most violent of all. The strong movements, of course, continued all the next day. - The blasts seemed to go from north to south. - No other phenomena could be observed. Almost all steamers felt the earthquake on the high seas."

Coquimbo (29° 55' S., 71° 25' W.):

According to the "Mercurio del Vapor", No. 542, the earthquake, which lasted 4 to 5 minutes, occurred about 8:25 min, p. m. of May 9, without any sound being heard. At 10 ½ o'clock the cry was heard, "the sea begins to leak!" The sea retreated far at that hour and when it returned, it rose over and reached the center of the harbor square. At 11 o'clock it came out with great force. The movement lasted until 1 o'clock in the afternoon of May 10, with the sea rising and falling to about 2 meters.

The Consul's report says: The earth tremors began to be felt in La Serena, in the Lyceum (29° 54' 11" S., 73° 39' 9" W., elevation 25 meters above sea level) at 8 o'clock 31 min. in the evening, mean time. (The time is taken according to the master clock, which is always accurately revised). The shock went from north to south, with expulsions from east to west. No underground noise preceded the shaking. The duration of the earthquake was 1 minute 58 seconds. The oscillatory motion of the earth was slow but very strong. A strong shock, which usually characterizes earthquakes, was not perceptible, rather the great extension of the oscillations and their striking slowness made the shaking comparable to the fluctuations that one feels when embarking in a little agitated sea. At the moment of the earthquake the sky was covered with rain clouds, the air was calm. The barometer stood at 762.9 mm, the thermometer at 15°8 C. (In Serena, because of the great distance from the sea, no observations could be made about the tidal movements of the sea).

The scanty information that was available about **Valparaiso** in the past has been considerably increased by a consular report and especially by the notes that Mr. J. C. Hilliger had recorded in Valparaiso and which he very kindly made available to the Consulate General in Valparaiso.

The earlier notes read (op. cit. p. 450): In Valparaiso on May 9 at about 8 ½ o'clock in the evening, according to another report at 8 o'clock 25 min. a prolonged but light earthquake took place. The following morning the sea showed an unusual movement, which continued on the 11th.

The Consulate report says: "The earth tremor occurred at 8:30 p.m. on May 9, 1877, and consisted of slow and regular fluctuations from east to west, of about 1 minute, more or less, duration. During the 10th and 11th, one noticed a forward and backward flow in the water of the harbor, at intervals of 15 to 15 minutes. High tide and low tide about 2.20 meters rising and falling.

The notes of Mr. Hilliger about the earthquake of May 9, 1877, bring so many remarkable details that they may be reproduced here in full:

"1. Extension of the vibration circle:

The movement of the earth was felt: north to the 11th or 10th degree south latitude and south to 35½°. It seems to have started from a central point, which is to be looked for about 21° 50' to 22° 20',[9]) how far the same is to be assumed as distant from the coast, is probably direct difficult to determine. The direction observed by me at Valparaiso from the oscillations of a free hanging lamp (pendulum about 8' long), which swung out of the lot about 3 inches to each side, was quite accurately N. 20° W. to S. 20° E. This would indicate the latitude of 22° and the longitude of 78°. About 450 nautical miles from the coast; which is nearly the longitude of the islands of Juan Fernandez and Felix & Ambrosia. I can't swear to 5° more or less westward deviation anyway. If one knew exactly the direction of the concussion in those places which are close to the central point, the determination of the position of the center would be more exact (!), but the indications from there are fluctuating. Some think that the direction was also N. - S., resp. S. - N. Others give a west-east direction. - How far to the east the movement made itself felt, I have not experienced, it does not seem to have extended over the Cordilleras.

2. type and strength of movement:

The southernmost place where a gentle, elongated, back-and-forth movement has been perceived is the port of Constitucion, located at 35° 19' in an estuary, built partly on alluvial soil and partly on secondary formation. The longitude is 72° 24'. The time of the earthquake is 8:30 o'clock. and the time of the sea's exit is 9:30. Reduced to the longitude of Tocopilla, near the central point, 70° 15', this gives 8 h 39-40 Min. and 9 h 40 Min. In Tocopilla, the earthquake occurred not later than 8 h 20 Min. and the sea's exit was 8 h 50 Min. The following results: Time for the propagation of the shaking from 22 to 35.° through 780 nautical miles 18 to 20 minutes time, but for the sea movement 50 minutes. - In contradiction with this is that one wants to have perceived the movement of the sea in Valparaiso on 33° 1' only about 11 o'clock at night, which would be against Constitucion 1 ½ hour delay. It is possible that the first rises of the sea were not noticed, since they were less high here at all than is reported from Constitucion, where the tide is reported to be 2 ½ - 3 m high, while in Valparaiso it did not exceed 1 ½ m. The time indications are also not to be considered accurate, since there are no standard clocks. Therefore, 5 minutes more or less are not to be considered at all, if it would depend on determining the time theoretically. - The movement of the earth in Valparaiso has been a very gentle, long-drawn-out one, a shifting back and forth with very weak and very long undulations. In my house, where usually every vibration is felt by a rattling of the windows and a small glass roof, as well as by a cracking of the walls, no one has noticed anything of the sort, and yet the shift has been so strong that the hanging lamp above our heads has swayed in an arc of 6"; the same thing took place in a neighboring house, both at 250' sea level, built on soft crumbled granite ground. In the city and on the sea, however, a slight shaking is perceived several times. Longitude 71° 40', time 8 o'clock 35 min.

Coquimbo, 29° 56' - 71° 20', weak earthquake, tide 1 ½ m.

Caldera (secondary shelly limestone on trachytic bedrock), 27° 3' - 70° 53', strong swaying of the ground, at 8 h 30 min. flooding of the shore with 2 ½ - 3 m alleged height at 9 h 15 min.

Chañaral, 26° 21' - 70° 50', strong swaying and shaking, N.- S., of the ground, which is partly sand of a dry river valley, partly trachytic rock. Flooding 9 h 10 min. with about 4 m vertical height; although some reports give higher numbers, I have perceived from my own view of the terrain that 12' is the highest that can be assumed, rather less.

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[9]) This would therefore be further south than Iquique, approximately in the area of Tocopilla.

Antofagasta, 23° 40' - 70° 30', on rocky ground. Violent and prolonged shaking of the ground in a north-south direction at 8 h 20 min. or 8 h 25 min. Flood height 20' or 6 m, great destruction of buildings and goods.

Mejillones, 23° 6' - 70° 31', sandy bottom partly already hardened to sandstone-like structure, in a 20 miles deep bay, which is open to the north, protected to the south by the peninsula of the same name. The earthquake here was extraordinarily violent, the shaking movement is given as going in north-south direction. People who live in west-east, or more correctly in NNW. - SSE. direction were thrown down. (This indicates a direction of the surge in this latter direction.) Time 8 h 20 min. – 8 h 25 min. The site is about 30' above sea level, yet part of it was washed away, consequently the tide rose 30 - 35' vertical.

Cobija, 22° 34' - 70° 17'. Earthquake exceptionally strong, most of the houses built of air bricks, as well as the church towers overturned or severely damaged. Shaking movement. Vertical height of the flood inundating the place 25 - 30 feet. Open coast.

Tocopilla, like Cobija, is located on trachytic rock, at 22° 5' S. and 70° 15' W. The movement of the ground was like in Cobija. Flood 30' high, the place entirely destroyed and washed away.

Guano ports Guanillos and Pabellon de Pica, 20° 50' - 21° S., 70° 14' W., located at the foot of the coastal mountains, on open coast, i.e. not near any indentation. Violent earthquake; shaking motion. Flood 25-30' high. Complete destruction of all wooden houses located to 35' above sea level. Loss of many lives (about 120). Ships lying here suffered much, 11 lost entirely, all others badly damaged.

Iquique, 20° 12' - 70° 10'. Very strong, shaking movement, S. - N., tide 12 - 15' high; more a rapid rise of the water than a tidal wave as in 1868. First tide 8 h 50 min., last at 12 h 30 min. Here, as in all the places previously mentioned, at least 4 floods have been observed, the first about 9, the last after 12 ½ o'clock.

Mejillones del Peru, 19° 50' - 70° 14', earthquake strong, flood 8'.

Pisagua, 19° 36' - 70° 12', located in a deep bay protected by a point protruding to the south, which is considered by some to be an ancient crater. The earthquake has been very violent here, as well as the tide has risen again higher than in Mejillones, 12-15' high.

Arica, 18° 28' - 70° 20', river valley. Earthquake as strong wave motion. Tide slightly north of the island in front of the harbor 20-25', at the city about 15' high.

Tacna, 18° 17' - 70°, located about 20 miles from the coast in the river valley, rolling bricks to significant depth. Earthquakes less violent, no significant damage to buildings, which are all built of air bricks.

Ilo, 17° 37' - 71 20'. Strong shaking, the place is on rocky ground. Flood 12-15' high.

In all ports north of Iquique, the time of the earthquake is given as 8 h 25 min. to 8 h 30 min., but in Iquique, where the time was probably best observed (!), **8h 20min**. Flood ½ hour later.

Islay. Strong shaking, swelling of the sea about 8'. Since the rocks rise vertically from the sea, the tide could not be observed.

Pisco, 13°43' - 76°12'. Terrain alluvial and sandy plain, shaking therefore very violent. Damage to overturned buildings. Sea emergence after 12 noon until 5 AM on the 10th; height about 10'.

Callao, 12°4' - 77°19'. Time of the earthquake 8 h 30 min (i.e. reduced to 70°14' equal to 8 h 58 min). The sea emergence occurred mainly at 5½ o'clock in the morning on the 10th, after violent movement and rising and falling of the sea, as well as strong currents in the harbor, had already been noticed since 1 o'clock at night.

There are no reports about the places north of Callao, at least I have not noted any, only that on the 10th early in the morning in the bay of Ancon the sea flooded the shores, how high and how much, is not stated. - In Callao and Lima the earthquake was not very strong, the movement was a prolonged to and fro pushing and shaking, but immediately suggested the severity of the same in other places closer to the center. - It should be noted that since April 15 there have been heavy rains and storms all along the coast, in such a way that from April 15 to May 2 more rain fell than normally in a whole year, or sometimes in two years! In Valparaiso, for example, 1½6 inches. These unusual rains took place as far north as Callao. Again, immediately after the earthquake, there was unusually heavy rain in the areas most affected. Also in 1868, rainstorms of unusual intensity had taken place in the otherwise rainless districts of the coast near the Tropic of Cancer. - The volcano Isluga, about 19° S., which emitted enormous masses of white steam with a suffocating sulfur smell for more than a year after August 1868, was active again in the same way after May 9. - What

has been written about unusual heat in the mines of Cobija and Tocopilla are fables. Likewise the burial of many miners in these mines. Three or four people may have died in the mines.

The above are short notes I wrote down in May and June of last year.

J. C. Hilliger."

In **Tomé**, Chile (36° 37.5' S., 73° 1' W.) (observation about 500 meters from the mouth of the small stream Collen), no earth tremors took place. The tidal movement began with an outflow of the sea at 12 midnight of the 9th and, in fact, 4 main surges took place, the first at midnight, the second at 2 a.m., the third at a little after 3 a.m., the fourth at about 6 a.m.. The second wave or swell was the largest, in the river the water rose about 75 cm, the first wave about 70 cm, the third and fourth about 60 cm. The movement of the sea lasted several days. Low and high tides alternated rapidly at intervals of ½ to 1½ hours. The ebb and flow of the tide were silent. The movement was comparable to slow breathing. (Observations by Consul D. Ulriksen.)

Also the earlier news about the observation of the phenomenon in **Concepcion**, Chile (36° 49' S., 73° 5' W.) and in the port cities **Talcahuano** (36° 42' 45" S., 73° 10' W.) and **Lota** (37° 5' S., 73° 11' W.) received confirmation, resp. extension by a consular report.

The earlier news read (op. cit. p. 459): In Concepcion on May 9 between 8 and 8½ o'clock in the evening a light but long lasting earthquake took place. At 12 o'clock the sea receded throughout Talcahuano Bay, and at 1 o'clock it rose again, here and at Concepcion over 1 m above the highest tide level. In Penco, lower down, a house was flooded and the water was up to 1¼ cuadra from the shore.

- E. Cuevas reported to the "Diario oficial" No. 65: 8 h 20 min. a long, but slow movement of the earth took place, without anything remarkable having occurred. But after more than 4 hours a true phenomenon occurred in Talcahuano: The sea began to retreat slowly, but in such an extraordinary way that at 1 o'clock this retreat took place up to 150 or more meters and at last, as is assured, some ships anchored in the bay were left on dry land. The population left their homes and fled to the hills. Thereupon the sea returned, as slowly as the fall had been, and at 2 h 30 min. in the morning the water rose about 3 m above its usual level without doing any damage. After an hour, it seems, the movement of retreat and rise continued, but little noticeable. Nevertheless, the railroad embankment is damaged and silted up. - Another news indicates that the noiseless shaking occurred at 8 h 14 min. and the first flood movement at 11 o'clock. The sea is said to have receded as far as Rocuan Island. The highest tide mark was exceeded by 8 or 10 feet. Thereupon very accelerated ebb took place; then the sea rose again with the same speed. The time between low and high tide is given as 12 to 15 minutes. The following transitions did not go higher than the first one. The rising and falling of the sea continued for a long time at the same speed, sinking more than usual, but not rising higher than usual.

In Lota, the sea overflowed at 2 h 12 min., or 2½ h in the morning, May 10, up to the watch, then receded so far that the last post of the quay remained dry; later the tide came in again. Earthquake was not felt. ("Revista del Sur".)

The report of the German Consulate at Concepcion now says the following: Observation at Concepcion and Talcahuano by port authorities, recorded at Lota from the recollection of eyewitnesses. In Concepcion only a slow, swaying movement was felt about 8 h 25 min. p. m. of the 9th; in Talcahuano no earth tremor is said to have been perceived. The shocks proceeded in Concepcion and Lota in the direction from north to south. The first flood movement occurred at Talcahuano and Lota on May 10, 1877, 12 h 30 min. a. m. (mean local time of Talcahuano) and began in the former place with a recession, in Lota, however, with an overflow. (At Talcahuano at 12:30 a.m. was the first recession, about 4 English feet below the ordinary maximum

of the tide, at 1:00 a.m. the first recession, about 6 English feet above the ordinary maximum of the tide. The movement then repeated itself at intervals of about half an hour until 3:00 a.m. and then passed about 7 English feet above the ordinary high tide mark and receded 7 feet below the ordinary maximum of the tide. (The highest level of the tide, of 1 m 95 cm, is said to have been at the second surge).

From 4 o'clock a. m. the movement decreased, recurring about every half hour, until on the third day the sea returned to normal.

In Lota there was a fourfold stepping out and stepping back; the first. three times, from 12½ to 6 o'clock a. m. , at equal intervals. At 10 o'clock a. m. the last and at the same time strongest oscillation took place, which rose 5 English feet above the high-water mark. The movement was in such a way that the sea at first went out a little, then retreated very far, and both were repeated less violently. The third time it happened to an even lesser degree. The sea then remained calm until 10 o'clock a.m., at which hour it slowly rose to the aforementioned maximum height without any previous return, and then slowly retreated again, so that at 11½ o'clock a.m. everything was as usual. During the duration of the phenomenon, the sea turned rapidly in circles (eddies), causing some ships to lose their anchors.

During the phenomenon, a high barometer reading was observed, as well as a light southerly breeze under completely clear skies.

The following reports are available from the German Viceconsulate in Coronel on the flood phenomena in **Arauco Bay**, south of Concepcion:

"At 8:30 in the evening of May 9, a faint, barely perceptible earth tremor was felt by several persons in Coronel. The movement was one from north to south. On May 10, from 2 a.m. to 9 a.m., the tide movement of the sea occurred; the same was a rising and falling of the sea, in the period of 50 minutes, more or less, a fourfold rise and fall was observed, producing a difference in sea level of 10 feet. The high water mark was exceeded by approximately 4 feet. At Coronel, according to a captain who went ashore at 2 o'clock, the sea had receded to such an extent that it was with difficulty that he could swing himself from the boat onto the steps at the wooden pier; on his return after about an hour, to his astonishment, the sea is so high that he gets into his boat with comfort. Between the island of Sta. Maria and Lavapie Point (at the western end of Arauco Bay), a small coastal beauty thought he could use the opportunity to get to Lebu; the captain later said that when he came with his boat into the narrows between Sta. Maria and Lavapie Point, the current pulled him in and out for several hours, i.e. toward the ocean and back into Arauco Bay, until he finally salvaged himself behind the headland of Llico.

The rise and fall of the sea at the four points of observation, **Coronel** (Puchoco Point, 37° 1' 20" S., 73° 11' 33" W.), **Lota**, **Arauco**, **Llico**, **was** uniform, i.e. as far as the height of the tidal movement was concerned, even on May 11 and 12 there was an exceptional rise and fall of the sea, although not to the same extent as on May 10.

The following reports are available from **Valdivia** through the consulate there: In the harbor of Valdivia, **Corral**, and in the country estate **la Ensenada**, situated about 2 English miles southeast of Corral on the bay, the flood movements were not accompanied by earthquakes. In the sheltered bay of Corral the movement was not noticed until daybreak of May 9 (10?) 6:50 a.m., while in la Ensenada, which is opposite the opening of Corral harbor in exact direction and consists of flat land, the movement was noticed as early as 4:00 a.m. The movement was accompanied by an earthquake. The tidal movement has begun with an overtopping of the sea. In the bay of Corral and in la Ensenada, on May 9, the water rose and fell in short intervals of 10 minutes during the whole day, while on May 10, longer pauses of 20 minutes, and especially in the evening, pauses of 30-40 minutes occurred. In Corral, the tidal movement reached the level of the ordinary high water; the level of the storm surges that occur here in winter was not reached. In the bay of la Ensenada, the tidal movement not only reached the height of the spring

and storm tides, but exceeded them by 1 and even 2 English feet. During the tide movement there was complete calm.

In Valdivia itself, the tidal wave was very little noticeable and was not accompanied by earth tremors, so that for this reason no observations were made there.

Fort Corral is located 39° 53' S. and 73° 29' W., according to Findlay.

From Corral the meteorological observations of May 1877 were kindly sent in. Also from Valdivia by Mr. C. Anwandter, who at the same time gave a list of the earthquakes that occurred in Valdivia.

The consular report from **Puerto Montt**, Llanquihue Province, Chile (41° 29' 45" S., 72° 54' 40" W. Gr.), states: "On May 9 and 10, 1877, teine earth tremors occurred here. (All earth tremors here always come from the east and go to the west).

In **Ancud** on the island of Chiloë, according to some Jesuit fathers, six flood movements took place on May 9 and seven ebb and flow movements on the 10th, every two hours. In Puerto Montt only one very insignificant movement was observed.

Through the kind courtesy of the fathers of the Jesuit monastery, the Consulate also received a list of the flood movements recorded by them during the first half of 1877. The movements were recorded by a self-registering tide gauge made by the Jesuits themselves, which unfortunately burned at the beginning of 1878. For the purposes of this study, the tables could not be used.

The report earlier from Ancud by the "Diario oficial" was: On the evening of May 9 from 11 - 3 o'clock the ships anchored in the local harbor noticed an unusual pitching, which was the cause that the bows of the ships turned from N. to S. from hour to hour. On the 10th, the tide at the quay rose and fell three times from 11 - 12 noon.

In **Ancon** (port report) (the location of "Ancon" could not be determined [10]), on the 11th (?) at 9:15 p.m., an earth tremor lasting two minutes was felt, which went from S. to N.. A dull roar (ruido sordo) was heard, which seemed to go from N. to S. The flood, which began with a rising, lasted from 2 - 6 a.m., in about 5 to 5 minutes. The first wave was the highest, reaching 4 - 5 feet in height.

At this point, the report of the Tahitian brigantine "Tawera" should be remembered. On May 8 (?) at 4 o'clock p.m., in a latitude of 35° S. and 104° 52' W., it felt a strong shock. ("Geogr. Magaz." 1877 p. 206). - Only by assuming that the time was May 10 and 4 o'clock a. m. (- 6 o'clock 18 min. a. m. Iquique time) this message could be utilized and would then, according to the calculations given below, give the speed of the wave of 204 nautical miles and a mean sea depth of 616 fathoms. -

From the points of the coast located north of Iquique, the following news are available:

From **Mejillones del Peru** (20° 8' 48" S., 70° 10' 32" W.), the port captain there reports: The SE.-NW. nudge was felt at 7:45 p.m. (?). There were three shocks, the second was the strongest and lasted 1 minute. The sea rose about 9 h 10 min. p. m. of the same night. The distance to which it retreated before the flooding was 18-20 feet, after its flood it rose above the beach about 10 feet. The flooding began with an ebb tide. Four fluctuations took place, of which the fourth was the strongest, at intervals of 4 - 8 minutes. The spring tides rose 6 feet, twice to 13 feet above the usual measure. Calm winds, some rain after the sea left.

The port captain Fr. Medina reported to Lima: At 8 o'clock 15 min. p. m. (!) the earth began to tremble; this lasted for 5 minutes. As a result of the earthquake, countless stones fell from the mountains. At 11 p.m. the sea inundated the city, killing several people and causing great damage. The water rose 9 - 10 feet.

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[10]) According to the courtesy of Dr. Krümmel, a "puerto menor" Ancon is located in Peru, 11° 47' 20" S., 79° 31' 44" W., and another Ancon in Ecuador.

At **Pisagua** (19° 36½' S., 70° 19' W.), according to the report of the port office, the first surge was felt at 8 o'clock 20 min. p. m. of May 9. The same passed from E. to W. At 11 o'clock p. m. a falling of the sea occurred; there were four oscillations, in 2, 3 and 10 hours intermediate time. The second as the highest rose 16 English feet.

The steamer "Coquimbo" felt on its journey from Arica to Pisagua on passing Cabo Gordo at 8 o'clock 31 min. a sudden violent, 55 seconds lasting shock ("South Pacific Times"). At the Cabo itself, according to the report of the Intendant of Atacama, a violent shock lasting 2½ minutes was noticed at 8 h 30 min.

At **Arica** (18° 28' S., 70° 24' W.), according to the "Deber" No. 550, the earthquake was felt at 8½ o'clock p. m. and shaking continued until 7 o'clock in the morning. The sea broke eight times and rose 39 feet, the greatest rise being at 4 a.m. May 10. The devastation wrought in this port by the earthquake and flood is described as truly horrific. The wreck of the "Wateree" stranded in the flood of 1868 was lifted up and carried away 2 miles further north along the coast. The tidal wave is said to have reached exactly the same height as in 1868.

Another report gives 8 h 25 min. as the beginning of the earthquake

The report of the Port Authority of Arica reports that the first shock occurred at 8:15 p.m. (mean local time), that earthquakes occurred all night at intervals, going in the direction of NW. - SE. At 9 o'clock p.m. local time the first flood took place; the sea came out and approximately up to the height of the quay; thereupon it retreated. Its first emergence took place at high tide. The floods had about 30 minutes intervals. The highest wave, the penultimate one, at 4:30 a.m. of May 10, reached 8.6 meters in height. (The current runs in the NW. - SE. direction).

According to the Tacna Consulate report, the earthquake in Arica occurred at 8:20 a.m. local mean time. The flood movement began at 9 o'clock with a sea run back of about ¼ nautical mile distance. The first four tidal waves occurred hourly from 9 p.m. to 12 o'clock, the fifth at 1½ a.m., the sixth at 3 a.m., and the last two at 4 a.m. and 5 a.m. The one at 4 o'clock a. m. was the largest, with a height of 40 to 45 feet above the high-water mark. The flood movement was circular in the Arica bosom, generally running S. to N. Although the night was pitch black, during the earthquake the northeastern to eastern horizon was red, as if there were a strong conflagration in the far distance. [11])

In **Tacna** (18° 36" S.) the earthquake occurred according to the consulate report at 8 h 23 min. p. m. to 8 h 25 min. mean local time. According to others at 8 h 24 min. to 8 h 26 min. It passed from SE to NW. Clockmakers state that the regulators whose pendulums moved in the indicated direction did not stop, while all pendulums with other movement stopped swinging. One observed pendulum moved without shocks at an angle of 35° from SW. to NE. (the directions without rectification of the deviation). Extraordinary barometer differences were not perceptible in observations made immediately after the earthquake.

Ilo, Port of Pacocha, Peru (17° 38' S., 71° 20' W.). Port report: 8:30 min. p.m. (according to ship's time of the English company and Fitzroi's charts) Earth tremor in the direction from S. to N. About ¼ hour after the tremor, the sea retreated first and then a big wave came. There were three large waves, ½ hour apart; the sea continued to move until 5 a.m.. During the retreat, the sea fell 20 feet below its usual level and rose as much afterwards. The third wave was the highest. The tide had not changed, nor was there anything else remarkable to observe.

From **Mollendo** (17° 1' 0" S., 72° 2' 0" W.), the Port Authority reports the earth tremor at 8 h 30 min. p.m. at intervals of about 1'30", coming from SSE. At 11 h 45 min. p. m. Beginning of flooding with falling of

[11]) This remark would perhaps confirm the various indications of an eruption of one of the volcanoes located in the interior.

the sea, Three oscillations at intervals of 10 - 15 minutes; mean height 2½ - 3 meters; the second was the highest.

The Consulate gives the time of the earth tremors for Mollendo and Islay as 8:15 p.m., according to the clocks of the Mollendo-Arequipa railroad, which are regulated every two weeks according to the altitude of the sun. The blasts seemed to come from S. The sea did not begin to go up until about 11½ o'clock p. m.; it rose about 7 feet higher than at the highest tide; its first fluctuations were not noticed. The waves seemed to come more from SSO. than from S. The sea was not particularly agitated on the 10th, but was exceptionally agitated on the 11th, 12th, and 13th.

At Islay (17° S., 72° 10' 15" W.) three waves occurred after the ground surge, 5 feet higher than usual, which destroyed the quay,

At **Tambo de Mora** (17°11 ' S., 72° 10' 15" W.), according to the port report, a slight earth tremor was noted at about 11 h 35 min. p.m. on May 9. The first and highest wave (10 feet higher than ordinary high tide) was noted at 1 h 40 min. Three oscillations of the sea took place, the second at 2 h 35 min. the third at 3 h 15 min. a. m. of the 10th; the last was at high tide. Until 3 h 50 min. p. m. the sea then continued to flood and ebb at intervals of 10 - 20 minutes.

The consular report from **Arequipa** (100 English miles from the coast) gives the onset of the earthquake at 8:19 p.m. (chronometer); the same lasted 3½ minutes. The movements of the ground were uniform and undulating, without being intermixed with strong shocks as in 1868, and therefore the city has not suffered any damage. It should also be noted that the sky, which is always very clear and uncloudy in the month of May, became overcast on the 8th and 9th, and the air was full of electricity, and that on these days violent snowstorms were discharged in the mountains overlying Arequipa, which does not usually occur at that time of year.

According to a correspondence to Consul A. Weis in Dresden, the earthquake occurred at 8½ o'clock and the tremors continued all night and the following days. The movement was also felt in the Cordillera, along the entire railroad line from Arequipa to Puno.

In the harbor of **Quilca**, Peru (16° 42' 20" S., 72° 31' 0" W.) a strong earthquake directed from S. to N. took place on May 9 at 8:40 p. m. (harbor office report). 10 minutes after the indicated time, a large wave rose on the beach, as the sea rose 300 meters beyond its limit. At the moment of the earthquake, the sea retreated 20 meters and then returned in the manner indicated. The sea remained agitated until the 13th. The sky was covered with small, dark rain clouds.

At the **Chincha Islands**, south of Pisco, no earth tremor was observed. The tidal movement began with a rise; the highest tidal wave was at 1 a. m. on the 10th and rose ½ foot higher than the highest tide, which here is 10 feet. (Port report.)

The national barque "Amalia" is reported from **Pisco:** At 11 h 30 min. p. m. of May 9, a strong roar was felt in the chains; an unusual movement of the sea had already been noticed since 8 o'clock. 1 h 45 min. a. m. strongest wave; the movement began with the returning tide. Two large waves took place, the second at 3 o'clock a. m., at the time of high tide. After that, smaller floods at intervals of 10-15 minutes, continuing until the 11th.

In the port of **Chala**, Arequipa Department (15° 48' S., 74° 30' W.), an earth tremor of about 1½ minutes duration was felt (port report) at 8:40 p. m. mean local time on the 9th, without a sound. The same went from S. to N. and "the earth swayed like a suspended hammock" Another shock did not occur. No flooding took place in Chala. But on the 14th (?) very early in the morning the sea began to move and at 10 o'clock in the morning there was a flood, which was horrible at noon and remained so until the 16th. There was no particular wave, the sea was at low tide when it began to rain, the tide rose a little higher than usual, 6 English feet greatest height.

About the disaster at **Callao** (12° 4' S., 77° 15' W.) the "South Pacific Times" reports: Soon after midnight of May 9, several persons on the sea here noticed the unusually agitated condition of the water in the wharf,

which became even more conspicuous with corresponding noise as morning approached. By 4 o'clock on the morning of the 10th, the water in the bai had risen and was soon washing over the walls of the dock, namely in the Muelle Darsena. The loss of human life is estimated at hundreds, that of property at millions. - In Callao, a weak earth tremor was felt at 8 h 30 min. - The sea showed unusual movement as early as 11 o'clock on the 9th, and shortly thereafter the bay filled with swirling currents that caused the various ships to turn around the anchor chains. At Callao the sea showed several separate rises, the largest of which was at 4 o'clock on the morning of the 10th. - "To call the movement a tidal wave seems to us an incorrect designation, since a wave includes undulatory movement, while the movement of the sea was a series of distinct rotational upheavals, which produced numerous cyclonic currents of great speed and strength and lasted for several hours." [12])

The Port Authority of Callao observed the rising of the sea after accurate timing (noon cannon signal) at 4:40 a.m. on May 10. The movement of the sea began during low tide. The highest rise was 10 English feet. The swirling currents continued with greater or lesser strength for three days.

No surge was felt in **Supe** Harbor (10° 49' S., 77° 44' W.). The first wave was observed at 4 a.m. (pocket watch, port report), at high tide. Movements occurred at ten-minute intervals for 24 hours. The second wave was the largest. The sea stepped 100 feet above the shallow beach, 20 feet further on the second tide and 3 feet higher than the first.

At **Casma** (9° 28' S., 78° 25' 35" W.) on the 9th at 1½2 o'clock midnight at high tide, just before high tide, a wave was noticed that exceeded 75 feet. The second wave was larger and flooded the goods and ships on the beach. The third (the largest) completely flooded the landing place and went close to the huts, which are 1800 Spanish feet away from the beach. The sea then receded again, but every two hours there was a tide that went up to the place that was reached the first time. This movement continued until the 11th. The houses on the shores are 6 feet above the level of the sea, the same have not suffered.

At **Samanco** (9° 15½' S.), the time of flood movement was not accurately observed. Waves rose 12 feet above mean height. No earth tremor.

Chimbote near Samanco. Report of the harbor office: 7 h 30 min. a. m. of the 9th earth tremor of 11 sec. duration, on the same day at 9 h 17 min. p. m. another one of 20 sec. duration. In this port, no wave was felt. The sea sank 2 1 English feet and rose 6 feet on the 10th at 9 h 50 min. a. m. No other movement was perceived.

In **Santa Harbor** (8° 58' S., 78° 38' W.) on May 9, 9 o'clock p. m. (mean time) a surge was felt coming from NW. At 3 a. m. of the 10th (mean time) rising sea in approximately two-hour periods, first at 1 a. m., then 3 a. m. and 7 a. m. 10 feet above mean high water; the last wave was the highest.

Salaverry, Peru (Port Authority report): No noticeable earth tremor. First wave action: subsidence of the sea at 11 o'clock. Ebb and flood lasted ¼ hour; continued until 2 a. m. of the 10th. 75 cm above mean high water; first wave was the largest.

In the port of **Huanchaco** (8° 5' 40" S., 79° 9' W.) no earth tremor was felt. From 2:30 to 3:00 a.m. on May 10, the tide began to ebb, which was about 30 meters higher than usual. Three striking tides of 12 to 12 hours (daily tides!). The sea rose up to 20 meters above its usual bed during the first extraordinary tide. The following tide decreased in height. The low tide was more conspicuous than the high tide, the ships that were anchored in 20 - 25 meters came to dry land.

At **Pacasmayo Harbor**, 7° 28' 40" S., 79° 28' 0" W., no earth tremor occurred. The sea motion began with a retreat about 7:45 min. a. m. Only one

[12]) At this point, the report from Ancon (p. 410) would have to be switched in.

wave came, which retreated to the ordinary level after two minutes. (Port report)

No earthquake was felt at **Tumbez** (3° 30" S., 80° 30½' W.); the tidal movement took place at high tide in S. - N. direction. At 11 a.m. was the largest wave, 20 minutes later the second; a third was not observed (Port Authority report).

Guayaquil, Ecuador, reported that no observations had been made about the phenomenon. - The consulates of Panama and San José, Costa Rica, reported that no extraordinary fluctuations of the sea had been observed there. Likewise, the report of the German Consulate General to Guatemala stated. -

The flood waves have also extended to the west coast of the North American continent, and there are news reports according to which the traces of the movement can be followed as far as San Francisco. (Report of the Coast Survey, Washington.)

Thus the "Star and Herald" Panama, of May 21, reports that on May 10 a flood wave inundated the state of Guerro, Mexico, and rose to the level of the Plaza at **Acapulco** (16° 51' N., 99° 50' W.). - According to reports from the officers of the "Lackwanna," an unusual and rapid rise of water took place in the harbor here on May 10 at about 10 o'clock in the morning. The water came up to the streets of the city. This phenomenon was followed by four more similar flood waves at intervals of 15 minutes, the water rising and falling by 3 feet each time. From noon to evening (4 p.m.) weak floods still took place, at intervals of 20 minutes. On May 11, rapid rising and falling of the tide was observed between 11 h min. and 11 h 40 min in the morning., with a second rise at 11:50 a.m. From noon to 4 p.m., five flood waves were observed at irregular intervals of 25-35 minutes.

The northernmost point from which a definite and accurate indication is available is Gaviota, **San Luis, Obispo co.** , south of San Francisco, (35° 10' N., 120° 40' W.), from which a dispatch of May 10 reports that here at 7 h 10 min. a. m. of the 10th the sea rose 12 feet, then receded, and within 20 minutes rose and fell three times. (Newspaper clipping, preserved by the "Weserzeitung.") -.

By a review of the above reports one soon becomes aware that the different data of one and the same place unfortunately often do not agree and that for this reason the determination of the earthquake center and the shaking circle does not have the exactness as would be desirable. On the other hand, these variations in the data for the later following surveys about the tide movement within the Pacific Ocean are, in view of the large distances, relatively only minor sources of error.

Since just from the points within the circle of the strongest shaking the data about the beginning of the earthquake differ very much, so the center of the earthquake and the extension of the area of the strongest shaking cannot be indicated with full certainty. The closest to the truth will probably be the determination that we have as a

Centrum or the place situated first to the Centrum the city

Iquique in Peru (20° 12½' S., 70° 14' W.) and as a

Time of the occurrence of the earthquake 8 h 20 min. p. m. of May 9, 1877. It is not improbable that the center was still somewhat more southward, approximately with the Pabellon de Pica located 0° 45' south of Iquique. From the observation of the flood phenomena and individual data about the direction of the earth tremors it will further result that the earthquake center was not at all on the mainland, but at a point somewhat westward from the coast. Its more exact position is not to be determined, however, also because of the not exact enough time determinations. About the depth of the earth under the surface of the earth no conclusions can be obtained. - For the following investigations it will have to be sufficient to assume the starting point of the earthquake in Iquique and the time of the beginning 8 h 20 min. p. m. IX.

The area of the strongest shaking, within which the - everywhere very long lasting - earthquake occurred at the same time and with the same intensity, at the same time accompanied by subterranean roar, cannot be stated

with certainty in its exact boundaries. It includes the following places: (Tacna), Arica, Pisagua, Mejillones del Peru, Iquique, Pabellon de Pica, Chanabaya, Punta de Lobos, Guanillos, Tocopilla, Cobija and Mejillones de Bolivia, as well as the places located in the interior of the country Tarapaca, Chacanche, Calama, Chiuchiu. This area is the Peruvian coastline that extends in a straight line in a north-south direction, in the extension of about five degrees of latitude. Its extension to the east, into the interior of the country, cannot be determined exactly because of the scanty news.

In general, the central area of the 1877 concussion was somewhat more southerly than that in 1868; at that time, as is well known, the center was Arica (18° 28' S.)

A tremor of the earth at all was felt in the area between Callao (12° 4' S.) and Coronel at Arauco Bay (37° 1' S.), that is, towards the extension of about 25 degrees of latitude.

It should be noted that some news reported a renewed activity of some volcanoes in the interior of the country. Several considered the volcano Ilaga (Isluga), located west of Iquique, as the originator of the earthquake. According to others ("Deutsche Nachr." and others) the volcanoes Llaima, Chillan (?), San Pedro (?), Llullaillaco, Cascanal and Colopi should have been seen in renewed activity. However, these news are to be taken up for the time being only with special caution.

As well as about the beginning of the earthquake, the data about the beginning of the tidal movement on the American coast differ. Also about the kind of the first movement there is unfortunately a great uncertainty of the reports; some state that the movement has begun with a running back, others, with an exit of the sea, a wave. When evaluating the notes, it should also be noted that in many cases the late hour of the day was not favorable for observing the initial movement, which was perhaps only weak at some points. The information about the number of waves that occurred and the duration of the time between the individual waves, about the height, and which was the largest, unfortunately offer too little complete material to allow a more detailed determination of the course of the wave motion, the times and places of the various interferences and the like. We get only a general picture of the tide movement, without being able to fix the individual moments.

In the following, those data about the beginning of the flood movement are briefly compiled, which seem to have some claim to accuracy. In the cases where several different data were available, all of them are given; the time is reduced to the mean local time of Iquique, whereby, according to the accuracy of the documents, the indication of the seconds and partly of single minutes was omitted. The designation W means that the first tide movement was observed as a lifting wave, the letter R indicates that the movement should have begun with a receding of the sea, thus a wave trough.

Iquique 8 h 25 min. p. m., 8 h 40 min., 8 h 50 min. W. (R.?)
Pabellon de Pica 8 h 25 min W.
Chanabaya 8 h 40 min W. or earlier R.
Punta de Lobos 8½ h, 8 h 40 R. W. 8 h 30. W.
Guanillos 8 h 30 min. R.
Tocopilla 8½ h, 8 h 35 W.
Cobija 8 h 38 min. w.
Caleta 8 h 40 min W.
Mejillones de Bolivia 8¾ h W.
Antofagasta approx. 8 h 40 min. R.
Caldera 9 h R., 9 h 30 min. W., approx. 11 h R.
Carrizal alto ca. 10 h R.
Carrizal bajo 10½ h R. (on it 10 h 40 min. W.)
Lota 12 h 40 min W.
Coronel 2 h 12 min. a. m. X. R.?
Corral 7 h W.
la Ensenada 4 h 10 min W.

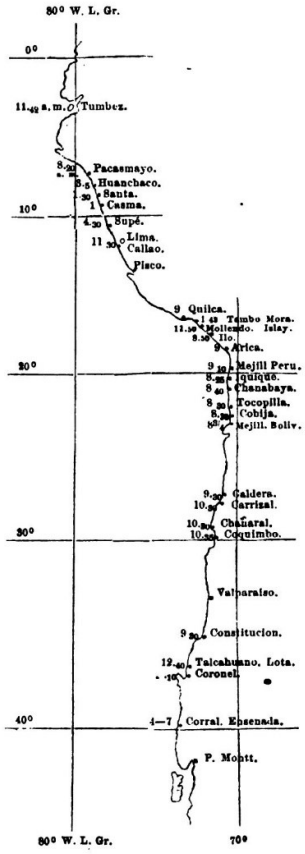
Mejillones del Peru 9 h 10 min. w. (previously R.).
Pisagua ? 11 h R.
Arica 9 a.m. W. (R.?)
Ilo approx. 8 h 50 min. R.
Mollendo 11 h 50 min. R,
Islay 11½ h.
Tambo de Mora ? 1 h 48 min W.
Quilca 9 h W. (previously R.)
Callao after 12½ h, 11 h 30 min (5 h 10 min W.).
Supé 4 h 30 min W.
Casma 1 h a. m. X. W.
Santa 1 h 30 min W.

Chañaral approx. 10 h R., approx. 10½ h W., 9¼ h W.
Coquimbo 10 h 35 min R.
Valparaiso ? 11 h.
Constitucion 9 h 30 min W.
Tomé 12 h10 min. a. m. X. W.
Talcahuano 12 h R., 12 h 40 min. R., 11 h 10 min. R.

Salaverry 11 h 35 min. p. m. R.
Huanchaco 3 h 5 min R.
Pacasmayo approx. 8 h 20 min. a. m. X. (?) R.
Tumbez 11 h. 40 min. a. m. X. W. (?)

Acapulco 12 noon X. W.
Opisbo 10 h. 30 min. a. m. X. W. (?)

For a more convenient overview, here is a sketch of the coastline affected by the earthquake and the flood movement with the places concerned, with indication of the time of onset of the flood movement at the individual places (reduced to mean Iquique time).



From the above data, using correctly the most probable ones, the following results about the flood phenomenon can be obtained.

At the places, which were affected by the strongest shock at the same time, thus at the places within the circle of the first and strongest shock, also the flood movement of the ocean occurred first and rather simultaneously. Admittedly, also here the data diverge in many ways, both with respect to the time and with respect to the way of the movement, namely whether it began with a wave or a retreat of the sea. It is not possible to construct the center, from which the movement started, from the combination of the places, at which the flood occurred simultaneously, by isorhachic lines. So much appears as certain that the center of the earth shock, and consequently also of the flood waves, was not located on the solid land, but some nautical miles (perhaps 50?) westward from the coast and namely southwestward from Iquique.

The phenomena of this tidal movement were pretty much the same as those of the seaquake caused by the earthquake of Arica on August 13, 1868.

The disturbance of the equilibrium in the Pacific Ocean caused by the earthquake manifested itself in a so-called lifting wave or forced positive wave (Russel), which propagated in concentric rings on all sides. This forced wave was followed by a wave trough, this was followed by a usually stronger second wave, and so on in multiple repetitions. The farther from the starting point, the easier these waves could be disturbed, be it by the influence of the seabed or land headlands and islands, be it by interference with waves which, thrown back from the shore, met them. To follow such processes in more detail would be an extremely rewarding investigation; unfortunately, this is not possible in the present case because of the insufficient material. Only from individual points there are exact reports that give us a detailed idea of the flood movement in its individual phases; here we refer back to them. - In many places within the first flood circle a retreat is indicated as beginning of the movement, from other points however again an elevation of the sea. It is possible that the first retreat corresponded to the lifting wave at the center.

In order to have a fixed starting point for the following calculations, we want to set as the beginning of the flood movement 8:25 p.m. of May 9 and as the place of this exit Iquique. We are aware of the fact that the actual beginning coincides with that of the earth tremor, i.e. 8 h 20 Min., and that the center is not Iquique itself, but a point somewhat to the southwest, from which the wave propagated within 5 minutes to Iquique and the neighboring places. Both data can not be determined more exactly and the error in relation to the starting point and time is so small compared to the fluctuating other data and then in relation to the significant distances that it is not too detrimental to the further results.

In the following, those data are used which seem to have the greatest probability. However, one can see how even in neighboring places the results of the calculation partly deviate so significantly from each other that the difference can only have its reason in the deviating data about the time of the onset of the tidal movement and is not due to local conditions. Thus, the information from Caldéra cannot be correct, from which a propagation speed of the wave of 380 nautical miles per hour would result, which would correspond to a mean sea depth of the ocean between Iquique and Caldéra of 2130 fathoms. A comparison with the calculations for other places of the coast shows that these values are considerably too large.

As is well known, the mean depth of the part of the ocean passed through can be calculated from the propagation speed of the wave with the help of the formulas of Airy or Russel[13]. These are respectively $h = (v/k)^2$ and $h = v^2/g$, where h is the mean depth of the ocean, v the velocity of the wave in feet, k the number 5.671 and g = 32.1908 Engl. feet.

As can be seen from the compilation of the calculations, the values found for the mean sea depth on the west coast of South America fluctuate within considerable limits; as noted above, this is due to the insufficiently precise premises of the calculation. The difference between the results of Acapulco and San Luis, Opisbo, according to which the tide reached Acapulco, which is closer, later than San Luis, which is much further north, is perhaps caused by the fact that the Galapagos archipelago stopped the wave off Acapulco by a considerable amount.

If one compares the found depth values (from the 8 points in South America on the average 544 fathoms and after San Luis, Opisbo 1440 fathoms) with the data on Petermann's depth map of the Great Ocean, it results that according to our results along the coast the edge of the first depth zone (0 - 1000 fathoms) should be wider than indicated on the map. Likewise, the mean depth between Peru and San Francisco would have to be shallower than assumed by Petermann. However, the few islands could be of disturbing influence here.

The calculations about the places on the American coast are compiled in the following table.

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[13]) Cf. V. Hochstetter, op. cit. p. 40.

	Distance*) from Iquique in sea miles.	First flood movement. Iquique time.	Duration The Journey of the wave.	Speed of the wave.		Average depth of the part of the ocean		
				nautical miles per hour.	English feet per second.	in English foot,		In fathoms, in the middle.
						Airy's formula.	Russel's formula	
Coquimbo	590	10h35M.p.m.IX.	2 hrs 10 min.	273	461.6	6625	6620	1104
Lota	1025	12„40„ a.m. X	4 „ 15 „	241.2	407.7	5169	5166	861
Coronel	1020	2„12„ a.m. X.	5 „ 47 „	177.5	300	2800	2798	467
LaEnsenada	1195	4„13„ a.m. X.	7 „ 48 „	155	262	2134	2132	355
Corral	1195	7„--„ a.m. X.	8 „ 35 „	140	236.7	1742	1741	290
Callao	633	11„30„ p.m.IX.	3 „ 5 „	205.5	347.5	3753	3751	625
Casma	800	1„--„ a.m. X.	4 „ 35 „	161.6	273	2317	2316	386
Huanchaco	892	3„ 5„ a.m. X.	6 „ 40 „	134	226.6	1596	1595	266
Acapulco	2825	12„--„ m. X.	15 „ 35 „	181.9	307.5	2939	2937	490
Obispo co.	4389	10„30„ a.m. X.	14 „ 5 „	311.8	527.2	8642	8636	1440

1) The direct distances of the different places of Iquique given here and later were all calculated from the spherical triangles.

Let us now move on to the news that has arrived from the various points in the Great Ocean.

The Kais. German Consul in Papeete, Tahiti, Mr. G. Godeffroy, brought the following valuable report:

"... With regard to the **Society Islands** I have nothing to mention, not the slightest influence of the said earthquake was perceptible here.

On the other hand, on the **Marquesas group**, especially on the islands of **Nuka-Hiva** and **Hiva-Oa**, a flood has taken place, which seems to me to be connected with the earthquake that occurred on the west coast of Peru because of the striking coincidence of the time.

After a prolonged unusual drought, the rainy season began in mid-March and reached its culmination between May 10 and 17. - All rivers and streams burst as a result of the rain flood that broke out over Nuka-Hiva. All bridges were washed away. - At **Taiohaë** (on Nuka-Hiva, 8° 55' 20" S., 140° 6' W.) there was a breach of the sea; on May 10, about 4 o'clock in the morning, the sea, which was incidentally quite calm, left its bed and penetrated the solid land to about 40 meters; immediately afterwards it retreated, so that 50 meters of its usual bed were drained. During 10 minutes one felt an oscillatory movement; sometimes the sea was very low, sometimes very high, and this change lasted the whole day. The average change of level can be estimated at 4 meters.

Much more significant was the sea flood in Anaho, the northeastern part of Nuka-Hiva. The sea penetrated 200 meters into the interior of the country and several houses were washed away.

The most terrible devastation, however, took place in Tahuku, Dominique Island (Hiva-Oa); this bay is bounded on both sides by precipitous rising cliffs, which is why the sea penetrated a very considerable distance into the interior.

This extraordinary movement of the sea was observed throughout the archipelago, but with different characters; for example, in Vaitahu and in Puamau there was no oscillatory movement, but the sea remained at a very low level throughout the day (May 10). "

In addition to the news about **Apia**, on the island of Upolu, Schiffer or Samoa Islands, 13° 49' S., 171° 41' W., which I owe to a communication

from Mr. J. C. Godeffroy in Hamburg, I received the following confirming note from the Kais. Consulate in Apia the following confirming note:

In Apia harbor, the tide movement occurred at about 5¼ - 5½ o'clock in the morning local mean time, i.e. Apia or Sydney time, on May 11 (i.e. May 10 Greenwich time); it was no longer possible to determine whether the tide movement had begun with an overtopping or receding of the sea. (In the tide movement of 1868, a receding was observed first.) Three main fluctuations in intervals of 10 - 15 minutes were particularly noticeable, the fourth was already significantly lower, but the movement continued throughout the day, gradually calming down. According to a feature on the post of a scourer standing on the beach, the sea rose about 49 English inches above the ordinary high-water mark, or about 35 inches above high-water mark at spring tides. It is no longer possible to determine which tidal wave was the largest.

The aforementioned letter of 11 May =10 May Greenwich time, to Mr. C. Godeffroy reads :

"Since this morning about 4½ o'clock (onset of low tide) we have had the effect of a tidal wave here in the sea; about 6 o'clock was the strongest rise and fall, probably about 12 feet or more. The spectacle repeated itself every 10 minutes and still continues at 8 o'clock. The inflow and outflow may still be estimated at about 5 to 6 feet, but is much less crowded and the change less rapid. - P. S. The flooding lasted with gradual decrease until about 12 o'clock noon (entry of the flood). Accidents have not happened here."

With a time difference of 6 hours 46 minutes with Iquique, the onset of the flood movement in Apia is thus 12 noon, or 11¼ a.m. of May 10.

The following reports on the flood phenomena in the **Sandwich Islands** are available through the "Hawaiian Gazette" of May 16, 23 and 30, 1877:

The tidal movement broke over the entire archipelago at the same time and was only not noticed at the different places at the same time because of the early time of day.

On the island of Hawaii the wave came to **Hilo** (19° 44' N., 155° 3' W.) according to the observations of Porter and Capt. Smithers at 4¾ o'clock in the morning in the direction of approximately NNE. in a straight line from Waiakea, destroying the greater part of the settlement, demolishing large houses and an iron bridge, carrying wooden buildings about ¼ mile away from the coast. The damage was particularly severe in Waiakea, which lies on the opposite side of the bay; Cocoanut Island was also flooded.

The height of the wave was estimated at 30 feet; according to Severance, it was 13.5 feet above the low-water mark, and at Waiakea, it was 16-17 feet.

According to Mr. Severance, the unusual oscillation of the sea in Hilo Bay was first observed at about 4 a.m., nearly 1 hour earlier, before the big wave came in. The sea fell and rose all day.

The extraordinary and rapidly following fluctuations are clearly evident from Mr. Severance's measurements ("Haw. Gaz. " May 23):

In the morning about 7 o'clock such a "tide" was determined by Severance. From its lowest ebb to its full flood, it took only 4 minutes and rose 14 feet vertically. It rose and fell about every 3 minutes throughout the day. In the afternoon at 3 o'clock, Mr. Severance again made measurements: The first tide made a height of 6 feet above high water mark in 10 minutes, it fell to a depth of 2 feet below low water mark in the same time; rose again to 8 feet above mean high tide height in 8 minutes and fell to low water in about 12 minutes; then rose to about 3 feet above high water in 15 minutes and fell in about the same time, rising and falling three times in one hour.

Still 12 hours after the big wave, at 4 p.m., the sea rose and fell 10 feet; the following day the rise was still about 5 feet ("Haw. Gaz." May 30).

At Kawaihae, on the west side of Hawaii, the difference between rise and fall was about 5 feet.

In the harbor of **Kahului** (west of the island of Maui, 20° 31' N., 156° 43' W.), about 4¾ o'clock in the morning of May 10, fishermen in the bay observed a retreat of the sea, which drained the whole bottom of the harbor; thereupon the sea ran in through the harbor opening like a river high and fast again, rising 4 or 5 feet above the ordinary high-water mark. A second wave was not so high as the first, the third still lower, but the fourth reached almost the same height as the first. The sea was still rising and falling more than usual on May 12, but the motion became calmer. - Another observer also gives 4 h 45 minutes as the time of the first movement of the sea.

Flood movement was also observed on the island of Kauai.

Honolulu (on the island of Oahu, 21° 28' N., 157° 55' W.): On May 10, about 20 minutes after 5 o'clock, it was noticed at the shipyards that the tide was going out with great violence, and by accurate measurements of pilot Babcock it was constatirt that it fell 21 inches in 5 minutes. At 6 o'clock the water returned, the sea rising 34 inches in 10 minutes. A similar inflow and outflow of tides continued throughout the day and night, gradually decreasing in magnitude. The largest difference between high and low tide was 58 inches in the harbor in the morning.

The Honolulu harbormaster reported to the German consul in Honolulu: The tidal wave was first noticed at 5 a.m. on May 10. The sea rose and fell within a few minutes, the same was lowest at 8 h 2 min. a. m., highest at 8 h 32 min. a. m., and the greatest fall was 4' 10". This rise and fall of the water lasted until 11 May noon, after which the usual ebb and flow resumed. Wind on 10 May NE. (Force No. 6), barometer 30.20, thermometer 75°, hygrometer 73°.

The difference between the highest and lowest water level is, according to the "Haw. Gaz. "The difference between the highest and lowest water levels at the various points is as follows:

Hilo, east side of Hawaii, 36 Feet.
Kealakekua Bay, west side, 30 F.
Kawaihae, do. 5 F.
Kahului, north side of Maui, 22 F.
Lahaina, south side do. do. 12 F.
Honolulu, south side of Oahu, 4 F. 10 in.
Nawiliwili, southeast side of Kauai, 3 F.

The "Hawaiian Gazette" of May 16, 1877, brings the following summary of the extraordinary floods observed in the Sandwich Islands in earlier times:

In 1819 - In 1837, on the evening of November 7, sudden retreat of the sea by 8 feet. Then a huge destructive wave in Hilo and Kahului. - May 17, 1841 same phenomenon, but less violent, fall of 3 feet. - August 13 and 14, 1868. difference between highest and lowest levels 5' 4".

On the **Chatam Islands** a terrible flood wave was noted by Th. Ritchie on the night of May 11; Old Jamie's place is partly washed away, the Waitangi Bridge was washed away. According to other reports the wave did not reach the height as in 1868. More exact news are missing.

In the **New Zealand** places the flood movements were observed in all navigable harbors and in the rivers lying in the flood area on the east coast of the North and South Islands, to a similar extent as in August 1868; although apparently less violent, but just as widespread and at some points more noticeable. By analogy with the August 1868 phenomenon, the flood movements here were immediately attributed to an earthquake phenomenon in the east. [14]) The "Lyttelton Times" and "Press", as well as the "Herald", from

[14]) Dr. Hector stated in the meeting of the Wellington Philosophical Society of July 21, 1877, after analogy of the seaquake of 1868, that the flood must have originated from an earthquake, which according to the calculation must have taken place about 8 o'clock p.m. of the 9th on the South American coast - a conjecture, which has been confirmed in the most evidential way!

which newspapers almost all of the following notes, some of which were published earlier (op. cit. p. 463), report that the phenomena were observed in the following places: Poverty Bay, Gisborne, Napier, Lyttelton, Akaroa, Timaru, Oamaru, Port Chalmers and Bluff. The phenomenon was observed after 7 a.m., Friday, May 11, 1877, the rise and fall varying from 3 to 8 feet (the latter in Poverty Bay). Ebb and flow took 15 minutes to 1 hour. From noon on May 12 to morning on the 14th, many more small fluctuations took place at irregular intervals.

On the west coast of New Zealand the phenomenon occurred so weakly that it was observed here at all only in the Buller River (41° 45' S., 172° 45' E.). Unfortunately, the more exact time data are missing just from here, so that one cannot determine the delay of the waves.

The individual places on the east coast in their order from north to south are as follows:

In **Auckland**, the tide rose to 9 inches on the morning of the 11th. - A report from Mr. E. B. Dickson in Auckland to the German Consulate there states that at almost all places the tide began to rise with an overtopping of the sea, only at Mangonui (in the north of the island) with a receding of the water. The height of the first high tide was 7 to 8 feet, the duration of the high tide about 8 minutes, the duration of the low tide just as long; the following waves were not over 3 feet high; in Tauranga the first wave over 3 feet, in Russell over 6 feet.

At **Tauranga** (37° 37' S., 176° 11' E.) a flood movement took place about 8 o'clock on the morning of May 11; the water rose 3 feet higher than usual in spring tides. This was followed by sudden falls in short intervals, which continued all day.

Poverty Bay (38° 40' S., 178° E.): A great flood movement took place in **Gisborne** all night of the 11th; on the morning of the 11th at 3 o'clock at ¾ ebb tide a flood wave came across the bay and rose 8 feet above the top of the hull "Go-a-head" causing a sudden rise of the river 3 to 4 feet. At 9 h 30 Min. a second wave entered the river, at 9 h 45 Min. another, and almost immediately a fourth. The water of the bay was very agitated.

According to the observations of the harbormaster at Gisborne (report of Mr. E. B. Dickson, Auckland, to the K. D. Consulate at Auckland), the first wave was at 7 a. m. (Wellington mean time), the second at 9 a. m., the third at 11 a. m., the fourth at 12 h 40 min. p. m., and the fifth at 2 h 30 min. p. m.

Wellington (41° 6' S., 174° 30' E.): On the morning of May 11, shortly before 7 o'clock, when it was a little more than ¾ low tide, an unusual tide movement was observed in the harbor of Wellington. A large mass of water suddenly broke into the bay, causing violent movement among the ships; in ¼ hour the tide had passed the ordinary high-water mark: thereupon it receded with equal rapidity, and in another 15 minutes the low-water mark was reached. From this time on, the tide continued to flow at intervals that gradually decreased from 15 minutes before 8 a.m. to 10 minutes before 10 a.m.. At 8 o'clock the difference was close to 5 feet, at 10 o'clock 2 feet. At noon, the intervals between low and high tide were only 7 minutes and the rise was 1 foot. Disturbances continued throughout the day, with high and low tides occurring a few 20 times during the period from 7 a. m. to 3 p. m.

In the **Cook Strait** the tidal movement was particularly noticeable in that the waves came from SSE. while the first one is said to have come from W. according to Capt. Lloyd's observation.

From **Kaiapoi** (north of Lyttelton) is reported May 12: During the day yesterday a number of flood waves moving up the Waimakariri, although the river was otherwise quite calm, caused no small sensation. The town is about 3 miles from the mouth and there the highest wave, coming in with great force (about 6 miles per hour), rose 2-3 feet at the swing bridge located in the center of town without doing any considerable damage. The first wave is said to have come at 6 o'clock a. m. and by 8 o'clock a. m. had been followed by three; the movement continued in prolonged intervals until noon. The sea was in violent motion in the morning. Also Saturday noon two subsequent waves are

said to have appeared in the river in Kaiapoi and the river was still moved by current during the afternoon.

The earlier news about the flood at Lyttelton (43° 37' S., 172° 45' E.) was increased by the following information from the K. D. Consulate in Christchurch, N. Zealand. According to the reliable observations of Mr. A. R. Webb at Lyttelton, the first flood movement was observed at Lyttelton at 9 h 5 min. a. m. of May 11, New Zealand mean time. Said gentleman writes to Dr. J. v. Haast in Christchurch: "The movement began with rising of the tidal wave. The wave rose 2 feet 9 inches at 9 h 5 min. At 9 h 10 min. it began to fall and fell 2 feet in 9 minutes. Advancing and receding every 10 minutes until between 4 and 5 in the afternoon, at which time the sea calmed to little more than ordinary motion. At half tide, about 11½ o'clock a. m., the sea was at its highest, 18 inches above the ordinary spring tide mark; the sea rose 9 feet 6 inches during the 2½ hours between 9 o'clock and 11½ o'clock a. m."

The Lyttelton Times and Press further note: "On the 11th early in the morning the inhabitants of the harbor were alarmed by the fact that, although the tide should have been low, the tide was higher than at ordinary high tide. As in 1868, the weather was clear and a light SW wind. At Lyttelton on May 11 at 2 o'clock p. m. the barometer stood at 29.75, the thermometer at 39; attention is further called to the fact that on the Tuesday before the barometer stood very low, namely 28.78. - At 7 o'clock a. m. (according to the "L. Times" about 7 h 30 min.) the water was observed to become very turbulent and turbid, rushing in upon the harbor with unusual rapidity, rising 18 inches per 7 minutes. At 9 a. m. the water rose and fell 3 feet every 5 minutes, and later 3 feet every 9 minutes; from 6 feet 9 inches to 9 feet 9 inches. At 10 o'clock a. m. at half tide it rose from 6 feet 9 inches to 11 feet 9 inches in a very short time; at 10 o'clock 40 min. it had fallen from 14 feet 6 inches to 13 feet in 5 minutes. At noon the disturbance decreased when nearly high water; the water remained very muddy. By 2 p.m. high water was. (17 feet, i.e., about 2 feet higher than ordinary high water.) The unusual movement continued into the night.

At 4 p.m., 2 hours after high water, the tide showed 16 feet and then fell again rapidly.

In Pigeon Bay, the disturbance was even more significant. The inflow of the tide, which was no less than 7 feet above the ordinary level, caused some damage.

A notice by Capt. Edwin in the Proceedings of the Wellington Philosophical Society, July 21, 1877 (transmitted by the K. D. Consulate at Wellington), states that a conspicuous retreat of the sea was observed at Manowara, Bay of Islands, at 5 o'clock on the morning of May 11: "P. McAlister, of Manowara, in the Bay of Islands, fastened their boat to the bank in a bay on the night of the 10th. When they returned at 5 o'clock in the morning, they found the bay and shoal thereby quite dry, although the tide should have been long above high water. While they were waiting, they heard a loud thunder-like noise and saw a large wave approaching... Afterwards, the water quickly fell again." - Maoris from the islands of the Bay watched as at 5 a.m. the water rose above 8 feet in a few minutes and it fluctuated several times at intervals of about 20 minutes until late in the evening.

Reported from **Le Bon's Bay** (east side of Banks Peninsula): The unusually high tide at 7 o'clock on Friday (11th) morning gave us a clear sign of some disturbance that had taken place. The waves came in long, heavy surges and immediately there was a rapid recession. The water occasionally receded so far that one could walk from the shore to the harbor causeway. At about 12 o'clock a wave came with such force that it swept away two tramway bridges and carried them away for some distance. During the day various waves flooded the land. During the high tide of the afternoon, a high wave caused new damage. On Saturday, the same state of affairs continued.

From **Akaroa** (43° 51' S., 172° 59' E.) it was telegraphed that the sea was very agitated during the whole day and the flood waves began about 1 o'clock a. m. (midnight). began, sometimes rising 7 feet in 5 minutes. At 3

o'clock p.m. the tide was at its highest, namely a full 10 feet above high-water mark, all houses on the coast were flooded. At 5 o'clock p. m. The movement subsided. The weather was windless.

At **Timaru**, the first wave was observed shortly after 7 a.m.. From that hour until late in the afternoon, the sea remained rapidly rising and falling, the drop apparently being 3 - 4 feet.

At **Port Chalmers**, the tide movement was noticed at daybreak, with the water swaying a few feet on the shore; this continued for several hours.

In Dunedin, the difference in the rise and fall of the tidal wave was 18 inches to 5 feet.

Oamaru: The water flooded violently off and on at intervals of about ¼ hour. In the morning, at about low water. the sea suddenly rose and in about 10 minutes it was 1 foot near the high water mark. The flooding lasted all morning. - About 12 noon the sea rushed into the bay with terrible force, destroying the strongly built wharves; in a few minutes the water rushed out of the bay again in swirling currents. By 12½ o'clock the current and the whirlpool had disappeared.

The tide was also observed on the **Australian coast**, and only on the parts from which the present New Zealand could not keep the tide. In the protected places of the southern part, in the colony of Victoria, in Queensland, there was no tide or at least it was so small that it was not observed: here, therefore, the present

Island masses broken the waves.

The consulate in Melbourne reports: "We have learned from the director of the local observatory that no effect of the earthquake has been noticed on the entire coast of the **colony of Victoria**. The telegraphic report from **Queenscliff** and **Wilson's Promontory** says: Nothing unusual noticed in the tides at Queenscliff. Wilson's Promontory: No change observed in the rise and fall of the tide on May 11.

The Queensland Consulate in Brisbane reports that the earthquake that occurred in Peru in May last year was not felt there in any way.

On the other hand, accurate and valuable observations from Sydney and Newcastle are available through the careful notes of Govern. Astronomer Mr. H. C. Rusell in Sydney. The aforementioned gentleman was kind enough to send his observations and exact copies of the records of the self-registering tide gauges in Sydney and Newcastle to the consulate there. I would like to express my best thanks for this valuable support.

The waves are said by Russell to have occurred at various points along the east coast between 29° and 37° latitude, but without being closely observed.

A telegram from Mr. Russell, dated May 11, 1877, Sydney astronom. and meterol. Observatory, says:

"Heavy flood waves in New Zealand this morning between Lyttelton and East Cape, at 5 o'clock to 7 o'clock a. m.

Similar waves reported from **Newcastle** at 5 o'clock a. m.; largest fall 25 inches at 11 h 30 min. a. m. Similar waves began at **Sydney at** 5 h 20 min. a. m.; largest fall 9½ inches at 2 h 45 min. p. m."

All other details are evident from the records of the tide gauges of Fort Denison in Sydney and Newcastle, which are accurately reproduced in photographic reduction on Plates 2 and 3.

Mr. Russell gives the following additional notes to these flood gauge records :

"The tide gauges in Sydney and Newcastle are both of the same construction, except that the one in Sydney is considerably larger than the one in Newcastle, showing 1 inch of paper per 1 hour, while the one in Newcastle gives only ¾ inch per hour. [15])

In Sydney, the tide gauge float is in a well driven into the solid rock bottom of an island in (Sydney) harbor; the tide water finds entrance to the well

[15]) Hence, of course, the curves on the Newcastle register steeper than on the Sydney.

through a tube that has been lowered under water at the lowest ebb tide. The harbor is enclosed by a lot of land and every wave that touches the coast is already strongly broken in the harbor. Therefore, the tide gauge in Sydney does not register the extremes of the waves as clearly as the one in Newcastle. For the same reason, not as many waves are recorded in Sydney as in Newcastle.

Newcastle is a seaport formed by the mouth of a large river, and the tide gauge is exposed to the action of all waves; even the small rippling waves are registered so that the tide curve becomes a broad shaded line. The float is not completely unprotected, but surrounded by loose ballast stones; these are too large to be moved by the water, but the water passes freely through their interstices, and since the harbor is not protected by land, the earthquake waves can enter it freely.

The clocks of both instruments are regulated according to Sydney mean time by a time ball.

It may be noted here that the Atlantic shoals occur in sudden adjacency to the east coast of Australia. To the east from Sydney harbor 100 fathoms are found to 20 miles, to the north the 100 fathom line extends farther from the coast, and to the south not more than 14 miles."

"The curves etc. on the Newcastle register are printed upside down (top to bottom) for the convenience of the harbor master, who uses the tide gauges to determine the depth of the water at any given time. The instrument is so placed that he can look at it from one side only."

The O-line of the deep water is never reached, it is only the 0-line for the measurements; it is therefore omitted on the photo-lithographic images to save space.

Newcastle 33° 4' S., 151° 45' E.

Sydney, Fort Denison, on Garden Island in Port Jackson, 33° 51½' S., 151° 15' E.

During the floods, there was nothing particularly remarkable about the weather.

An examination of the flood registers reveals the following:

Sydney, Fort Denison: At 5 h 20 min. a. m. of May 11 (i. e. at 2 h 35 min. p. m. of the 10th mean Iquique time) the regular curve of the tide is disturbed by the appearance of a sudden wave (i. e. as in 1868 beginning of the phenomenon with a lifting wave). This is followed after about 40 minutes, shortly before 6 o'clock a.m., by a second wave. The second wave is followed by an even larger third wave at 6 h 35 min., with a rapidly following ebb tide; the fourth wave at 45 minutes is less high; it is followed by a deep ebb tide, which is interrupted again at 7 h 30 min. by a weak wave. These floods continue in a similar manner as they progress, except that now disturbances by interference waves occur from time to time, e.g., between 12 and 1½ o'clock noon, at 2 o'clock p.m., at the flood wave at 6 o'clock p.m., and so on. Gradually, the floods become weaker and weaker until they almost disappeared on May 13. All these floods have shown themselves as disturbances of the usual tide only insofar as they zigzagged the usual tide curve in rapid succession, but without occurring so intensively and extensively that they could have changed the general course of the lunisolar ebb and flow. The lowest water levels (below the 2-foot line) are recorded at 2½ o'clock a. m. of the 13th, at 2 o'clock p. m. of the 13th, and 3½ o'clock a. m. of the 14th. The highest floods (above 6 feet) were at 8 o'clock p. m. of the 11th, 7½ o'clock p. m. of the 12th, and 8½ o'clock p. m. of the 13th. These points of greatest high water are so situated that between each such high tide was a lunisolar tide which, with its zigzag bulges caused by the seaquake (which, in relation to the general, lunisolar main movement, we might in a sense call "secondary tides") did not exceed the average height.

The tide register of Newcastle shows us the beginning of the movement also in the form of a wave at 5 h 20 min. a. m. of the 11th day. After rapid low tide the first wave is followed in 40 minutes by a second, larger one, this after again about 40 minutes by a third still larger one and in approx. 20 - 25 minutes by a fourth, of the same height. Then, after a low tide, a fifth one. The sixth wave after 8 o'clock shows three bulges on the crest of its curve, caused by three interference waves. Also many of the following wave valleys often show subordinate elevations. Again, the two largest high

tides (over 6 feet), about 7 o'clock p. m. of the 11th and 8½ o'clock p. m. of the 12th, leave between them a high tide not exceeding the ordinary height of the daily lunisolar tides. The lowest ebb (only 11 inches above 0) was just before 12 noon of the 11th.

The sheet of May 13/14 unfortunately did not come into my hands, but here, too, the end of the movement on May 13 was not in sight.

The tidal waves of the seaquake also reached the **Japanese coast.**

A letter from Professor E. Knipping in the "Geogr. Mittheilungen" of 1877, p. 894 reports the following: "The wave seems to have arrived here in Japan on May 14 and to have been noticed on the whole east coast from Hakodate to Sagami. In the morning between 9 and 10 o'clock the tide rose so rapidly in the bay of **Kamaishi** (39° 16' 30" N., 141° 52' 50" E.) that the villages on both sides of the bay were soon under water and the inhabitants fled hastily to the hills Then the water sank again just as quickly as it had risen. At 12 o'clock noon and then at 2 o'clock in the afternoon the same phenomenon repeated itself in short pauses, until between 5 and 6 o'clock in the afternoon the sea rose and fell again 10 feet every 5 minutes. The exact time of the end is not given, only noted that at midnight the sea was calm again. Inside and outside the bay the sea was as smooth as glass during the apparition, the weather fine..."

The "Japan Gazette" and "Hiogo News" bring the following news from **Hakodate** (41° 50' N., 140° 50' E.): On May 11 (Friday; most newspapers give the 14th) at 11 h 30 min. in the morning the sea suddenly dropped very low, but after 10 minutes rose above 7 feet and continued to drop and rise all afternoon, at intervals of 20 minutes. Between 2 h 30 min. and 2 h 35 min. p.m., the wave reached its greatest height, and the water flooded the low-lying districts of the city. From 3 o'clock on, the rise and fall gradually diminished, and by sunset the sea had calmed down again. The greatest difference between the highest and lowest water is reported to be about 8 feet; each ebb and flood took about 10 minutes.

Professor E. Naumann in Yeddo was also kind enough to send me the following translation from a Japanese newspaper:

"We would like to mention here a curious piece of news in recent times. On May 11, 1877, the tide was supposed to come in a little later than 4 o'clock p.m., and when the sea water fell by about 1 foot, it began to rise again rapidly by about 2 feet. The people living on the sea and on the river banks were very surprised about this and suspected the approach of the great earthquake. They had been very anxious about this phenomenon; at last the water fell soon after. Opposite the bridge Eitaibashi of Fukagawa lives an old skipper who is over 70 years old. According to him, he had observed such an apparition once about 20-30 years ago.

The following was reported from Kadsusa (Katsura, 35° 20' N., 140° 40' E.): On the 11th of this month, the fishermen were full of jubilation over the large and successful catch of fish. At this time, suddenly at 12 o'clock, large waves approached the coast and washed away the nets and fish lying on the shore. Since the sea became calm soon after, everyone went back to the sea to fish. At 4 o'clock p.m., big waves came again, and the old and young, women and men, who were crawling on the shore, were in great confusion and fear. Suddenly the coast turned into a flat sea. Among the people, children and old people were dragged away with the waves to the sea with great wailing and screaming and ended their lives. Some fled with great danger to the hills and saved their lives. It was very sad to see the large number of dead and wounded in the villages. No one died in the village of Kitaidzumi. - On the 12th of this month, the floods came suddenly again in Yokohama and everyone feared that it was the harbinger of the earthquake. Also near Mori-oka, in the land of Rikuchin, a heavy rain began to fall that same evening and the water volume of the Kitagamigawa River increased. On the 13th, the water exceeded the usual height by 10 feet. - A man from Toshu had sent a letter saying, "From the 11th to the 15th, the ebb and flow of the sea water (tides) had undergone a change, and from time to time large waves came." -

The essential data from the various points in the Pacific Ocean and the results of the calculations already given above are summarized in the following table for a better overview:

Place of observation.	Direct distance from Iquique in sea miles.	Occurrence of the flood phenomenon after Iquique time.	Duration of the journey of the tidal wave.	Speed of the wave in		Average depth of the traversed part of the ocean		
				Sea miles per hour.	English feet per sec.	In fathom according to the formula of		In fathom in the middle
						Airy.	Russel.	
Taiohaë, Marquesas Islands	4086	8H.40M. a.m.X.	12hrs15M.	333.5	563.5	9884	9875	1647
Apia, Samoa Islands	5740	Aprx. 12h m. X	15½ hrs	361	610.4	11585	11575	1930
Hilo, Sandwich	5526	10h24M.a.m.X.	14 hrs	395	667.9	13871	13858	2310
Islands	5628	10½h a. m. X.	14hrs 5M.	399.3	675.2	14175	14163	2361
Kahului, "	5712	10h50M.a.m.X.	14hrs25M.	396	669.7	13946	13933	2319
Honolulu, "	5657	2h40M.p.m.X.	18hrs15M.	310	524.2	8544.3	8536.3	1430
Wellington, N. Seeld.	5641	2h48M.p.m.X.	18hrs23M.	307.4	519.8	8401.5	8393.7	1400
Lyttelton, "	6800	2h32M.p.m.X.	18hrs 7M.	374.4	633	12459	12447	2075
Newcastle, Austral.	6782	2h35M.p.m.X.	18hrs10M.	373.4	631.4	12396	12384	2065
Sydney, "	8790	7h20M.p.m.X.	22hrs55M.	383.8	649	13097	13084	2182
Kamaishi, Japan.	8760	9h25M.p.m.X.	25 hrs	350.4	592.5	10916	10906	1818
Hakodate, "	8939	9h50M.p.m.X.	25hrs15M.	358	604.9	11377	11367	1895
Kadsusa, "								

For comparison, the table containing the results of the investigations of y. Hochstetter's investigations on the seaquake of 1868.

Way of the estern wave.	Distance in nautical miles.	Duration of the journey of the first wave.	Speed of the wave in sea miles per hour	Mean depth of the ocean in fathoms.
Arica-Valdivia	1420	5hrs 0M.	284	1190
" -Chatam-Isl.	5520	15hrs19M.	360	1912
" -Lyttelton	6120	19hrs18M.	316	1473
" -Rapa	4057	11hrs11M.	362	1933
" -Newcastle	7380	22hrs28M.	319	1501
" -Apia	5760	16hrs 2M.	358	1891
" -Hilo	5400	14hrs25M.	329	} 2882
"Honolulu	5580	12hrs37M.	442	

The investigations made in the foregoing allow a comparison with the calculations which were made on the basis of the tide movement in 1868. In general, there is a satisfactory agreement, except for the depth values for the part of the ocean at the American coast.

The flood wave passed the Great Ocean within 23 to 25 hours (Japan), resp. 18½ hours (New Zealand and Australia), and arrived at the intermediate stations, according to the distance of the same and possible obstacles on the way, in an earlier time. That Sydney and Newcastle should have been reached by the tide earlier than the points of the New Zealand east coast further to the east is in any case not probable; it can be assumed that the movement to New Zealand has already occurred somewhat earlier than indicated.

Because of the incompleteness of the individual data, a more specific illumination of the questions belonging here would not have sufficient success. Therefore, we must be content with the above detailed data, which in part give a very precise and clear overview of the phenomena at the places

concerned, to state the general result that the flood movement in its nature and its propagation with that, which was produced by the earthquake of Arica on August 13, 1868, possessed a great coincidence.

Like the tidal wave of 1868, the one generated in May 1877 spread through the Great Ocean with the same speed as the lunisolar tides, and it was followed by secondary waves, interfering in part, which took two to three days for their gradual equalization.

We are content to refer to the above observations and the few remarks on p. 40 (422), as well as to the mentioned work of v. Hochstetter and the conclusions drawn by Schmick[16]) from the seaquake of 1868.

The observations on the propagation velocity of the tidal wave give us a mean to calculate the mean depths of the parts of the ocean traversed by the wave. The depths are given on the two tables, as they were determined according to the formulas of Airy and Rüssel; in the last column are the average numbers from the two results, expressed in fathoms (à 6 feet English).

Of interest is a comparison of the results obtained from our observations with the depth map of the Great Ocean published by A. Petermann[17]) on the basis of the depth measurements made by the expeditions of the "Tuscarora", the "Challenger" and the "Gazelle".

Based on our results along the American coast, both north and south of Iquique, the zone of shallower depths, from 0 - 1000 feet and from 1000 - 2000 feet, will have to be assumed somewhat wider than given on the map.

Since there is no obstacle in the way of the wave on the direct route to the Sandwich Islands, one can assume that the result obtained here is quite correct. Our value of over 2300 fathoms depth also corresponds to Petermann's data.

In contrast, we get a shallower depth on the route to the Marquesas Islands, about 1650 fathoms.

The result for Apia, Samoa Islands, of nearly 2000 fathoms may be influenced by the small coral islands in the way here.

In contrast, the figure of over 1400 fathoms average depth of the ocean between Peru and New Zealand would again have more justification.

However, it should probably be noted here that the time specification might have to be changed by quite a bit.

Australia also has a relatively shallow depth, from 2000 to 2200 fathoms. As can be seen from the map, there are several areas of different depths on the way, which must influence the overall result in such a way that the above average value is achieved. The comparison of the depths on the way from Peru to Japan shows that our result (approx. 2000 fathoms) does not correspond to the data of the map; the average value according to the map would have to be considerably larger because of the different, perhaps too arbitrarily limited, larger depth districts (Belknap, Ammen, Tuscaroa depth).[18])

A surprising phenomenon is still reported as a consequence of the earthquake from some parts of the affected coastal areas. A few days after the earthquake, heavy downpours fell there, although this time is usually very poor in precipitation. A private message from Arequipa to Consul Weis, currently in Dresden, says: "A few days after the earthquake, nature here had a completely different appearance. Arequipa, as is well known, always enjoys clear weather in the month of May, but after the earthquake dark, heavy clouds hung over Arequipa and heavy downpours took place several days afterward."

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[16]) J.H. Schmick, Das Fluthphänomen. Leipzig 1874. p. 19 f.

[17]) Geographische Mittheilungen 1877, p. 125, pl. 7.

[18]) Compare also about this the explanations in the recently published writing : O. Krümmel : Versuch einer vergleichenden Morphologie der Meeresräume. Leipzig 1879. p. 79f.

Two months later, Capt. Clampitt reported July 28 that the entire southern coast for several hundred miles, otherwise always dry and devoid of all vegetation, had been transformed into a formal flower garden as a result of the abundant rain after the earthquake. ("S. Pacif. Times," August 13, 1877.) Chile also experienced heavy rains and flooding in June.

Similar phenomena were also observed in some places after the earthquake of 1868. We leave here the extract of an article of Mr. W. Frick in Valdivia, which was published in the "Patria" (of Valparaiso) of February 25, 1869, as well as in the "Chilote" (of Ancud) No. 26 and 27 under the title "efectos del terremento del Perú" and of which Mr. Frick kindly sent a translation.

Frick considers the excessive rainfall observed in Chile that spring and summer, and mainly in the southern provinces, to be consequences of the earthquake in question. According to the notes of Mr. Anwandter, the amount of rain in Valdivia was

	In the spring months of Septbr, Octbr, Novbr.	In Decbr.	Throughout the year
1852	0.553 m.	0.097 m.	---
1853	0.527	0.012	2.862 m.
1854	0.398	0.063	2.990
1855	0.278	0.231	2.574
1856	0.330	0.125	2.722
1857	0.649	0.124	3.217
1858	0.470	0.012	2.724
1859	0.305	0.014	2.536
1860	0.500	0.028	3.064
1861	0.339	0.017	2.661
1862	0.685	0.145	3.254
1863	0.206	0.128	1.837
1864	0.464	0.204	2.636
1865	0.656	0.111	2.767
1866	0.417	0.030	2.664
1867	0.394	0.164	2.468
1868	0.668	0.308	3.573
Means of 16 years:	448 Mm.	94 Mm.	2,732 Met.

In the spring of 1868, 220 mm of rain fell, almost half as much as the average, in December 214 mm, and in the year as a whole 841 mm more than the average. The rainy year 1862, which was characterized by its excessive downpours, delivered 146 mm less in its last four months than the last four months of 1868.

The rainfall in Puerto Montt in 1868 was also surprisingly large. In the last four months of 1868, 993 mm of water fell, i.e. 17 mm more than in Valdivia and 280 mm more than the amount of rain in the same months of 1862. (From September to December 1862, 713 mm fell here, whereas in 1861 only 447.) In December 1868, 375 mm fell in Puerto Montt, 118 in 1862 and only 47 mm in 1861.

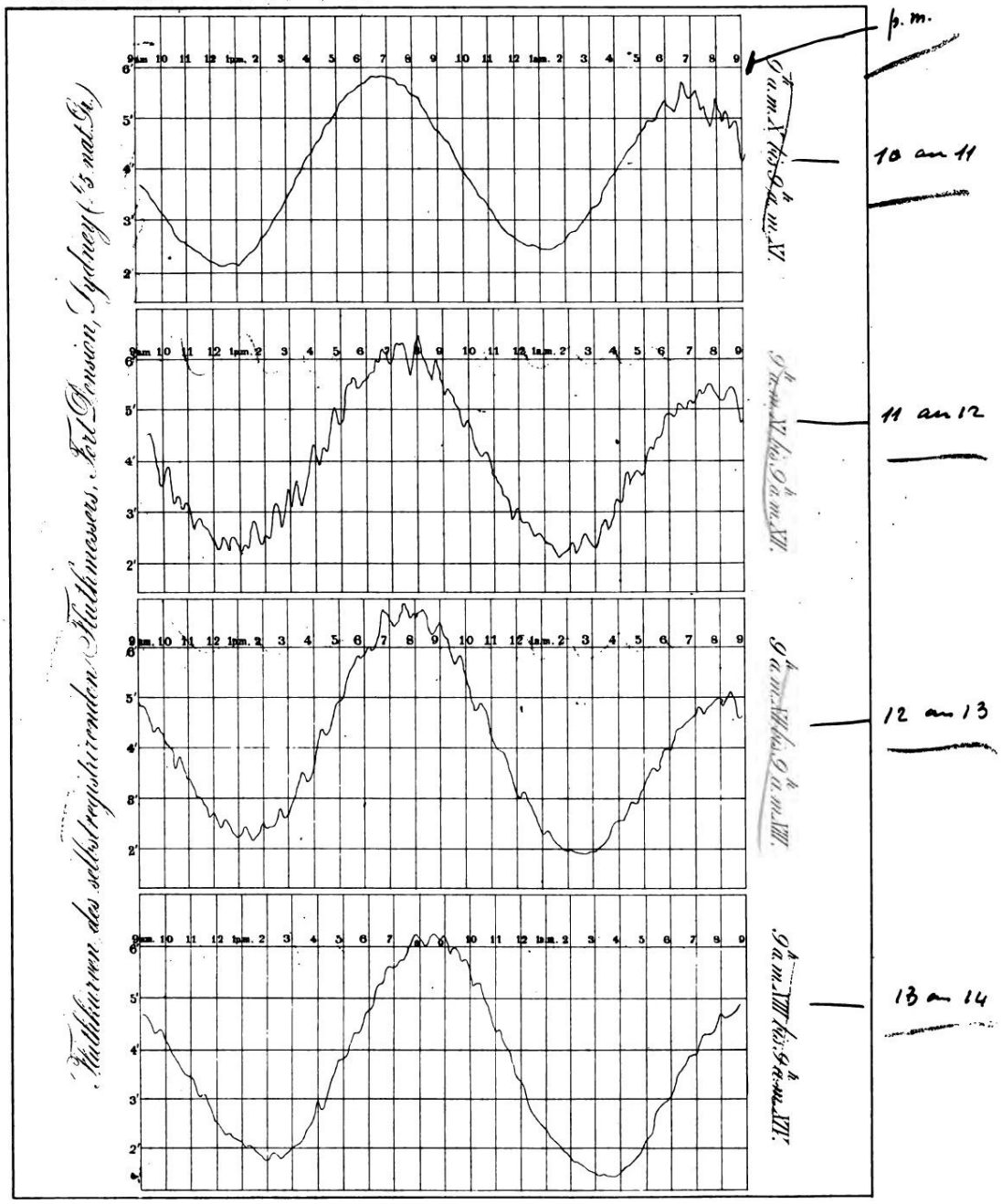
December 1868 was also exceedingly rainy in Ancud, with over 322 mm.

To explain this phenomenon, Mr. Frick cites the enormous quantities of water vapor which escape from volcanoes during eruptions and which, according to him, are the cause of earthquakes; during and after earthquakes, these vapors escape at the earth's surface or at the bottom of the sea and in both cases provide a considerable increase in the water vapor content of the air.

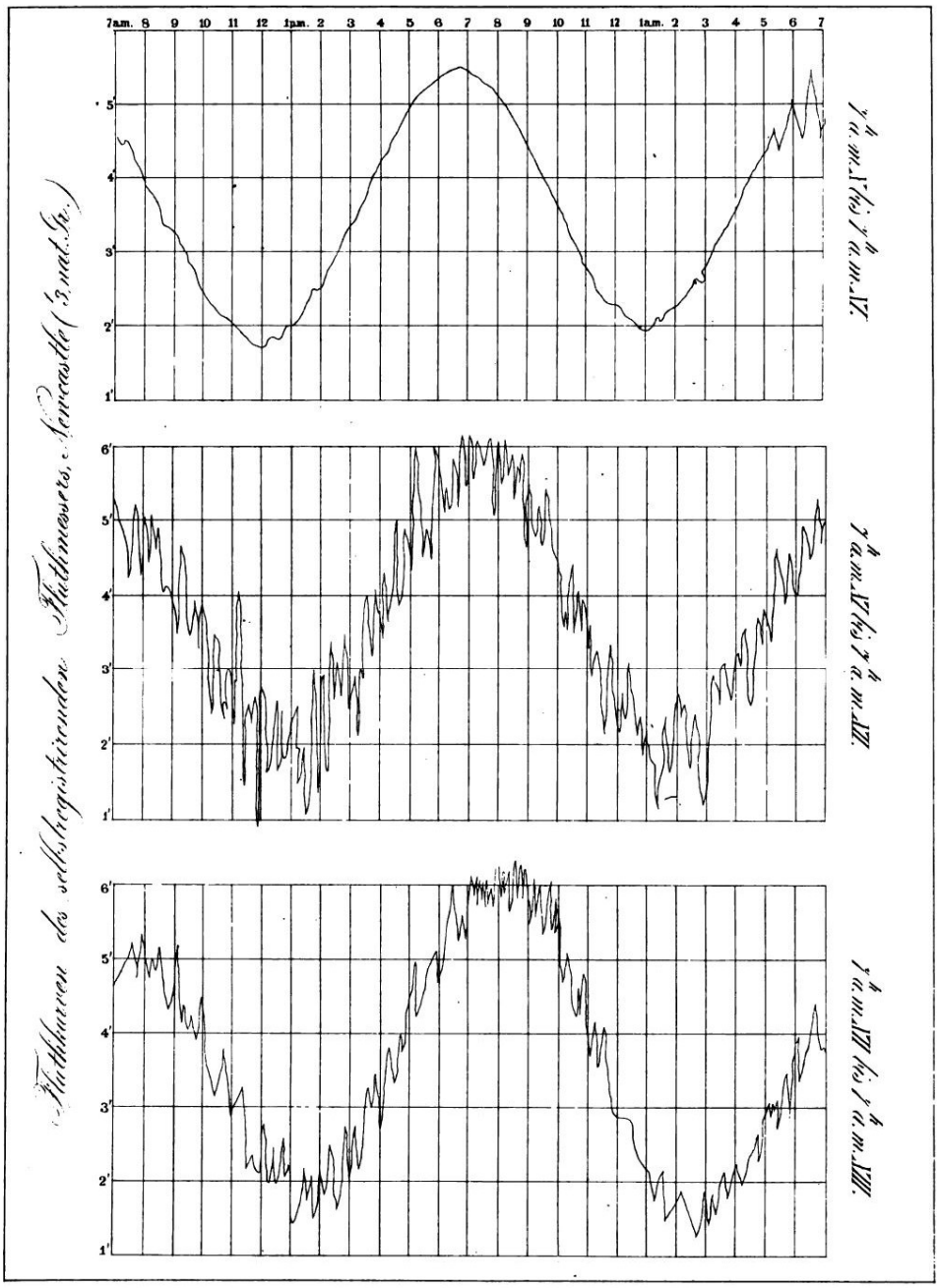
The traces of the seaquake of May 9, 1877, seem to have remained on the coast of Chile for a long time. Among the scattered news concerning it, a note in the South Pacific Times of January 8, 1878, states that at various places sudden waves were observed that rose several meters above the highest tide; furthermore, violent currents and sudden movements occurred in the sea. It is assumed that significant changes in the bed of the Great Ocean have taken place.

A phenomenon, which seems to have been analogous to the great seaquake of May 1877, is still reported in a report of the "Deutsche Nachrichten", Valparaiso, January 12, 1878, which we want to add here:

Caldera, January 6, 1878: "Towards the end of December we noticed here a little perceptible, but 1 minute 40 seconds lasting swaying of the earth, which was repeated in the night of January 1 or 2, if I am not mistaken, in even greater duration, but weaker, so that it was noticed only by a few. Since that first earthquake, the Great Ocean began to move in a peculiar way, which ended in an unusual spring tide." ... The regular spring tides at the time of the solstices had already taken place at the end of November and beginning of December. The new floods that began toward Christmas followed a decidedly westerly direction..." This extraordinary movement of the water masses reached its peak on January 2 and 3, when the sea rose about 1 foot higher than the tidal wave of May 9... At the same time, currents drifting from west to land formed in the sea, drifting landward at a speed of 6 to 8 nautical miles per hour. ... In harmony with these phenomenal tides are the atmospheric fluctuations. What has not happened in living memory is happening this summer. At the end of December it rained for more than 2 hours and on the 5th and 6th of January in the morning it was very foggy. All these events took place without any noticeable storms. In general, the temperature of the sea water in the whole past year, especially in the past winter, was between 1¾ and 2° Réaumur on average higher than in the previous year. Therefore, the past winter was significantly milder, averaging 4° R. than the previous one."



E. Geinitz, Das Erdbeben von Iquique vom 9. Mai 1877. Taf. 2.



E. Geinitz, Das Erdbeben von Iquique vom 9. Mai 1877. Taf. 3.