The earthquake in the Chilean province of Atacama
on November 10, 1922.

By A. Sieberg and B. Gutenberg.

On the night of November 10-11, 1923, all of the earth's seismometers recorded a worldquake of exceptional strength. It was immediately clear that the source of the earthquake must have been in Chile.

However, the first determinations of the source were very imprecise. The late Chilean seismologist Montessus de Ballore, for example, believed that the epicenter of the earthquake was located about 120 km from the true source, a determination that could only be based on a single seismometer recording in Santiago de Chile. The French earthquake service in Strasbourg searched for the source on the basis of the recordings at 18 European earthquake stations at a location no less than 600 km away from the true source. The following investigations show that the epicenter of the quake, which occurred at 11^h 33^m in the evening, was located near the town of Vallenar, inland.

The widespread assumption that the epicenter is to be found in the sea must be rejected.

The fact that so few lives were lost despite the magnitude of the quake - perhaps 600 were killed - is due to the fact that the quake affected sparsely populated areas.

We are particularly grateful that the Reichsanstalt für Erdbebenforschung received a wealth of observation material through its foreign service, which made it possible to process the earthquake accurately. We are particularly indebted to Prof. Dr. J. Brüggen in Santiago de Chile, who carried out extensive investigations into the earthquake and handed over the collected material to the Reichsanstalt. It was mainly through his efforts that it was possible to carry out a detailed macroseismic investigation of the earthquake.

The macroseismic processing of the earthquake was carried out by Regierungsrat Prof. Dr. Sieberg, while the processing of the seismometer recordings, which we owe to the domestic and foreign members of the German Seismological Society as well as several other earthquake observatories, was obligingly undertaken by Dr. Gutenberg in Darmstadt. The laborious graphic reproduction of the seismograms was carried out by Miss Töpfer.

O. Hecker.

Part one.

The processing of macroseismic observations.

By A. Sieberg.

I. The shaking area of the earthquake.

The center of the earthquake covers the southern section of the Atacama Desert between the Copiapo River and the Cordillera de Doña Ana, which connects the Andes chain with the Cordon del Romero belonging to the Coastal Cordillera, as well as the uninhabited western slope of the Andes at an undetermined latitude. The northern boundary of the macroseismic debris area is unknown; however, we know that its southern boundary intersects the coast between Valdivia and Puerto Montt, which corresponds to a range of about 1400 km in this direction. In spite of the rather uncertain course of the isostatic lines, which can only be drawn very schematically due to the thin network of observation sites, the old empirical fact seems to be confirmed again that the large axis of the shaking area follows the strike of the mountains, while across the strike a faster decrease of the perceptible earthquake strength to the east and west is unmistakable. In this case, however, it is unfortunately impossible to judge whether the different decrease of the earthquake strength in azimuth is only an apparent one, caused by the fact that the subsurface conditions strongly influence the attenuation of the earthquake energy, or whether the true earthquake strength actually decreases faster across the strike than in the strike direction. In any case, it is noticeable that the shaking area with the isostasy of lower degrees crosses the entire continent as far as the Atlantic Ocean at the mouth of La Plata, which would correspond to a range of far more than 1500-1600 km in this direction. The fact that the magnitude of the earthquake in Buenos Aires and La Plata was definitely of the Vth degree gives us pause for thought. One would almost think of a trigger earthquake in the east, whose shaking area merges somewhere in the Pampa with that of the main earthquake. As there are no sufficient time data for the earthquake in the east and the quake strength cannot be determined in the critical intermediate area, this important question cannot be answered. For some time it was rumored that the Easter Island, which enters the open ocean at an epicentral distance of no less than 3800 km, had sunk as a result of the earthquake. This rumor, against which the experts were very sceptical from the very beginning, was declared false by the barque "Falcon" after her return from Easter Island; as was to be expected, the quake was not even felt there.

II The effects of earthquakes

in the area of destruction (1) give the following picture, which is of fundamental importance for determining the epicenter.

Tab. I. Earthquake effects in the main shaking area.

Location	Epicentral distance*) Δ km	Population	Dead people		Wounded people	Building		Quake-strong I-XII
			S	%		damaged	uninhabitable	
Vallenar	58	6 000	333	5.6	600	all	all	XI
Good Loncomilla	70	?	4	?	?	all	all	XI
Freirina	90	2 600	12 80	3.6 ?	15	all but 1		X
El Transito	41	?	2	?	?	?	?	X
San Felix	54	?	6	?	?	?	?	X
San Antonio	72	700	?	?	?	all	almost all	X
Tierra Amarilla	113	1 000	?	?	?	all	almost all	X
Copiapo	128	11 000	64	0.6	100	all	85 %	IX
Huasco	72	420	12	2.9	?	all but 3		IX
Rivadavia	167	?	?	?	?	almost all	many	IX
Vicuna	176	1 700	.	.	?	all	some	IX
Yerba Buena	51	?	1	?	?	most	many	IX
Carrizal Alto	87	1 000	.	.	.	numerous	?	VIII
La Serena	186	15 000	.	.	3	90 %	30	VIII
Carrizal Bajo	109	1 000	.	.	?	numerous	?	VII
Caldera	172	2 500	.	.	?	some	?	VII
Rodeo	224	?	.	.	.	some	.	VII
Chañaral	89	2 000	.	.	.	few	.	VI-VII
Coquimbo	196	15 000	.	.	.	.	.	VI

*) The epicenter was assumed to be the one determined seismometrically by B. Gutenberg. The epicenter distances are determined according to the map sheets 1:500000, Republica de Chile, Oficina de Mensura de Tierras, which the Reichsanstalt is indebted to J. Brüggen in Santiago de Chile.

XI degree: Of the few towns located in the central area of the earthquake, Vallenar suffered the most. This small town of around 6000 inhabitants, 384 meters high on both banks of the Huasco River, was almost completely destroyed; only the church remained in good condition. The debris killed 333 people, i.e. 5½ percent of the population, and more than 600 people suffered more or less serious injuries. Numerous cracks formed in the ground, from which water and mud gushed out. Four people lost their lives in the collapse of the neighboring Loncomilla estate. Near the Fonda Paona estate, on the very high and steep banks of the Huasco River formed by older gravels, a piece of land planted with eucalyptus trees, 300 meters long, slid 200 meters without the trees falling.

X. Grade: The effects of the quake were only slightly less severe in the small town of Freirina, which is also in the Huasco Valley and had only 2600 inhabitants. All but one of the houses here were destroyed, 12 people were killed and 15 seriously wounded; there were also 80 other casualties in the surrounding area. Inland, on the western edge of the Andes, several people were killed in both El Transito and San Felix, a sign of considerable building destruction, although this is not specified. The quake effects on the upper reaches of the Copiapo River were of the same magnitude. In San Antonio, the terminus of the railroad at 1000 m above sea level, from where a crossing over the Andes to Argentina leads, all the walls collapsed and fields and paths were destroyed due to the resulting rifts. It is impassable. The mining village of Tierra Amarilla, located lower down, hardly had any houses left in a habitable condition. Cracks in the ground of various lengths, widths and depths, from which water gushed out in places, gaped open, and railroad tracks were bent by subsidence of the ground; landslides and rockfalls fell from the neighboring slopes. In the mines, tunnels collapsed. Some people claim to have observed serpentine electrical discharges at the same time as the earthquake.

IX. Degree: The beautifully laid out town of Copiapo (11,000 inhabitants) also suffered considerably, but not as badly as the villages mentioned so far. 40% of the buildings were completely destroyed immediately, including the parish church and the theater, a further 45% had to be torn down due to their dilapidated condition; but the remaining 15%, including the directorate, the court, the savings bank, the post office and the telegraph office could be made habitable again by repairing the damage. Sliding and tearing of the ground exposed a number of bodies in the general cemetery. According to the numerous reports, the earthquake in Copiapo occurred as a series of wave movements lasting about 3 minutes with intermittent vertical shocks that threw many fleeing people to the ground. Choking dust swirled up from the collapsing buildings, burying 64 dead and around 100 seriously injured under the rubble. Some residents claimed to have seen red flames like lightning, but others strongly denied this. Immediately after the quake, the moon broke through the dense cloud cover for a short time, and two hours later a light drizzle set in, a rare phenomenon for the area. The effects of the quake in the port village of Huasco at the mouth of the river of the same name, which despite its 420 inhabitants has good public buildings and copper smelters, were of roughly the same magnitude. All but three of the houses collapsed, but they could no longer be moved. On the Elqui river, in the well laid out town of Vicuña, no house was left without cracks and some houses had to be demolished, while those of inferior construction almost all fell victim to the quake. The boys' secondary school, another school, the governorate building and the police office were also completely destroyed; the church was severely damaged. However, there were no fatalities. Further up the Elqui Valley there was also no lack of serious damage to buildings. Many houses collapsed and the others became uninhabitable. In particular, the enclosing walls (pircas) of the fields, which are made of round stones and can offer little resistance to earth tremors, collapsed everywhere. In the mountain village of Rivadavia in particular, the quake caused extensive damage, although this is not described in detail in the reports. In Yerba Buena, many houses collapsed, killing 1 inhabitant.

VIII. Carrizal Alto, whose 1000 inhabitants live from mining and smelting, has been badly damaged. We get a better insight into the effects of the earthquakes further south. They were quite considerable in the relatively large town of La Serena (15,000 inhabitants), which is located about 4 km from the coast on stepped terraces of the Elqui River. 90% of the houses were damaged by Riese, 30 buildings became uninhabitable, including the military hospital; the directorate was badly damaged. Several houses started to burn. As a result of falling pylons, the power lines were interrupted in several places. Some inhabitants claim that there were electrical discharges at the same time as the earthquake, which is vigorously denied by others. It seems certain that there were neither disturbances of the earth's magnetism nor earth currents. On the north bank of the river, cracks in the ground opened up and water leaked out; nevertheless, wells and springs behaved normally.

Grade VII: In the case of the severe damage that occurred in the port city of Carrizal Bajo, 36 km from Carrizal Alto and almost as large, it is not clear from the reports to what extent it was caused by the earthquake or the seismic surge. The earthquake damage in Caldera is said to have been considerable; no details have been reported. The steamer "Flora", passing off the coast at Caldera, felt a seaquake that caused great panic among the crew.

We know from one place in the inter-Andean plateaus, namely Rodeo in the Iglesia depression, that damage to buildings has occurred, consisting of the collapse of walls, the falling off of cornices and the like.

VI degree: Of the places in this isoseis zone, only Coquimbo should be mentioned because it is barely more than 10 km away from La Serena and is, as it were, its harbor. Here the earthquake only occurred as a "temblor", which did not cause any significant damage to buildings, although cracks appeared in the ground in several places. On the other hand, the city suffered from the devastating effects of the seismic waves in a very unusual way.

Remarks on the construction method in northern Chile. A study by Bergassessor Linnemann (2), which deals with the consequences of the Copiapo earthquake of December 4, 1918, is important for the assessment of the effects of the earthquake. The following results are reported:

"The oldest and cheapest houses in the rainless north, in which the poor population lives, are the "tapiales" They are used for outer walls as well as for the most important inner walls. They consist of blocks 1 m high, 1.5 m wide and 60 cm thick, which are made from clayey material deposited by the Copiap6o river, only by pressing and shaping. The blocks are stacked up to a height of 2 m, usually without any reinforcement or mortar. In most cases, no care is taken to use straw to increase the resistance of the material, which is quite loose due to the large amount of sand it contains. Usually a few rows of "adobes", air-dried bricks measuring 30 x 60 x 10 cm made of the same material, are placed on top of these blocks; the rafters rest on these. The walls are covered on the outside with a thin layer of clay. The roof, which is usually flat, also consists of a reinforcement covered with reed or cane in the other types of construction. To protect it from wind and rain, it is also covered with a thin layer of clay. This deteriorates over time, but not everywhere; it must therefore be repaired every two years, which is done by smearing a new layer of clay on the roof each time. In the course of a few years, very thick layers of clay form, which jeopardize the stability and are very little resistant to vibrations. A second type of construction, much used because of its cheapness, are the adobe houses, whose material is the same as that of the tapiales, but the walls are thinner, so that the whole building is lighter. The erection of the adobes and their superficial covering with clay is also the same, and often a half-timbered construction is made with wood. This modification forms in a way a transition to modern constructions, which are more expensive and preferably made of cane and brea. The "brea", a shrub, is gathered in thin bundles and placed between vertical poles that are quite close to each other; then everything is covered with a layer of clay in the usual way. The cohesion is much greater in this case. If you need "guayaquil tubes", nail the tube sticks horizontally between the vertical beams, one on top of the other. In this way, layers of tubes are created, one inside and one outside; the cavity between them is not filled. This construction method is very durable and, thanks to its elasticity, very resistant to vibrations. However, it is not very common due to its high cost, as the pipe has to be imported from Ecuador. This type of construction is mainly found in commercial buildings and in the private homes of the wealthy social classes.*

On the occasion of the Copiapo quake of December 4, 1918, Linnemann examined 1630 houses, of which 440 = 26.8% were made of tapiales, 349 = 21.3% of adobes, 405 = 24.7% of brea and 446 = 27.2% of quayaquil cane. The quake damage was distributed among these as shown in Table II.

The twelve-part Mercalli-Cancani scale in Sieberg's edition (3) was used as the basis for determining the earthquake intensity. Due to the small number of observation sites, the isoclines in the accompanying map Fig. 1 could only be drawn very schematically, whereby it must be taken into account that the main shaking area, the Atacama Desert, is very sparsely populated and has only a few larger, contiguous settlements. Under these circumstances, it would be a fruitless endeavor to try to determine any correlation between the effects of the earthquakes and the geological structure of the terrain, especially since the settlements are located almost exclusively in the river valleys, whose moist alluvial plains form the fertile oases, so to speak, in the vast expanses of the rain-poor and sterile desert. The general picture of earthquake propagation would not change significantly even if one were to attribute a higher or lower earthquake intensity by ½-1 degree to one place or another on the basis of the reported earthquake effects, as has been done here.

Tab II Damage to buildings during the Copiapo earthquake of December 4, 1918, according to Linnemann.

Design	Number of houses	Completely destroyed %	Heavily damaged %	Little damaged %
Tapiales	440	56.6	31.4	12.0
Adobe	349	16.3	30.4	53.3
Brea	405	8.4	20.0	71.6
Guayaquil cane	446	0.9	5.6	93.5

The epicenter. The most important result of the macroseismic investigation of our earthquake is the finding that the earthquake originated in the continental parts of northern Chile, about 110 km from the coast. All macroseismic evidence indicates that the epicenter could not have been far from Vallenar, in the inland direction. This is evidenced by the marked decrease in earthquake strength from the western edge of the Andes mountain range towards the coast; this decrease is not only that of the apparent earthquake strength, which is influenced by the geological-tectonic subsurface conditions, but also that of the true earthquake strength, although a numerical value of the subsurface coefficients (4) cannot be determined in this case. The location of the epicenter cannot be determined more precisely from a macroseismic point of view because there are no towns in the area in question and therefore no means of observation. It is certainly not a mere coincidence that the data collected by. B. Gutenberg in Darmstadt, independently of me in Jena, has led to a result (p. 31) on the basis of numerous and in part quite flawless instrumental records, which the second part of this publication contains, which shows an agreement with that of the macroseismic investigation that could not be better expected.

The light phenomena. That in Copiape, Tierra Amarilla and La Serena light phenomena were occasionally observed in the atmosphere during the earthquake can hardly be doubted, although some people deny it. But in this case, too, there is nothing to suggest that the glow had anything to do with the nature of the earthquake; for, as we shall see, a very simple and more obvious interpretation suffices. It has been reported from La Serena that fires broke out as a result of the earthquake and that the pylons of the electric cables fell, which must have caused short circuits. Widerschein explains the lighting up of the firmament easily and adequately. Short-circuits of the electric wires vibrating in the earthquake must also be expected in Tierra Amarilla and Copiapo, although there is no explicit mention of this. We also know from Copiapo that a dense blanket of low rain clouds favored the reflection.

III The cause of the earthquake.

In addition to the expressly attested calmness of the neighboring volcanoes, all signs, namely the enormous size of the macro- and microseismic debris areas, indicate without further ado that we are dealing with a dislocation earthquake. This is what we call the physical consequences of every geological development of a disturbance (dislocation) of the layer structure (tectonics) in the brittle earth's skin as a result of overripe stress conditions. The nature of the tectonic processes that in this case may have led to the accumulation of potential energy and its eventual conversion into the kinetic energy of the earthquake vibrations will be examined below. The key to our understanding is provided by the structure of the western margin of South America south of the Tropic of Capricorn, especially in the light of the research results that we owe to G. Steinmann (5) in Bonn and his students as well as Walther Penck (6).

Fig. 1: Overview map of the main shaking area.

The general structure of Chile. From a purely orographic point of view, this western section of South America is divided into four narrow, meridional strips, which also show fundamental differences in their internal structure. They are discussed in order from east to west:

1) The Cordillera of the Andes is a folded high mountain range whose first beginnings emerged during the Triassic from a Mesozoic geosynclinal sea. At that time, and in particular from the older Tertiary onwards, new fold strands were constantly added to older mountain ranges by thrusting from the west, welding the older ones even closer together. In more recent times, fracture fragmentation was added, which led mainly to the formation of longitudinal fractures, and to a lesser extent to transverse fractures. The fracture fragmentation was associated with the abundant emission of magma, so that numerous mighty volcanoes, active and extinct, are superimposed on the mountains like foreign bodies.

2) The Westandine foreland accompanies the western foot of the mountain range as a narrow strip of flat or hilly land. Its subsoil consists mainly of flat-lying Mesozoic rocks. The details of its construction and formation will continue to occupy us in detail.

3) The Coastal Cordillera is, as R. A. Philippi (7) points out, a broad ridge with an undulating surface, composed of old crystalline rocks, mainly granitic. This ridge, interrupted in places, runs from the island of Chiloe along the entire southeast coast of the continent to the south of Taltal, where it extends into the sea at Punta Ballena. The granites of the coastal Cordillera decompose easily because they contain a lot of feldspar. This is why these granite mountains are usually rounded, have gentle slopes, low heights or even form slabs with an undulating surface, especially in the north; they tend to slope most steeply towards the sea.

4) A narrow deep-sea channel of more than 4 km depth accompanies the coast at a short distance. It contains the greatest depths of the Southeast Pacific Ocean, such as the Richard Deep (7635 m) in the Atacama Trench and the Haeckel Deep (5667 m) in the Valparaiso Trench.

According to Steinmann, Brüggen (8) and others, this division of the earth's crust into meridional stripes is the result of Young Tertiary fracture fragmentation. In the process, the floes on the longitudinal fractures shifted in a vertical direction with the result that the subsidence process was interrupted by phases of localized uplift. Consequently, the term coastal cordillera is incorrect, as this is not a folded mountain range, but a horst. The West Andean Foreland with a length of about 6000 km and a width of 100-200 km corresponds with the part submerged under the sea in the Taltal-Arica Gap to the East African Rift System with its continuation in the Red Sea and the Jordan Rift. The fracture character of the Great Chilean Longitudinal Valley between Santiago and Puerto Montt, which continues southwards in the ocean sound between the mainland and the offshore island series, has long been claimed and has recently been proven by J. Brüggen. Here we are dealing with a rift valley similar to the Upper Rhine Valley rift between the Black Forest and the Vosges. North of Santiago, in the province of Aconcagua, the West Andean foreland becomes mountainous, because many transverse ridges advance from the Andes towards the coastal Cordillera. But these transverse ridges, at an almost constant altitude of around 1200-1300 m, have a series of low inlets that can hardly be interpreted as anything other than the northern continuation of the Great Chilean Longitudinal Valley.

The tectonics of the Atacama. The main area of shaking in our quake, the Atacama Desert, is the northern section of the West Andean Foreland, including the Coastal Cordillera. The latter already recedes strongly in the surface image here, especially as it is covered by young sediments on the stretch between the Huasco River and Caldera. These consist mainly of Eocene, i.e. young Tertiary coastal deposits, mostly fossil-rich sandstones with clayey binders. At Caldera, Quaternary deposits are spread over a wide area in almost horizontal layers that are slightly inclined towards the sea. Behind the rather steep coast, a sandy desert rises in relatively gentle steps up to the foot of the Andes, which rise abruptly from the desert. According to Pissis, eruptive rock masses of various ages can be found in the subsoil alongside clods of red sandstone and Mesozoic limestone.

Already. E. Sueß (9) compared the structure of the Atacama with that of the Californian Longitudinal Valley, and more recent researchers, above all Steinmann, see it as a continuation of the rift valley of the Great Chilean Longitudinal Valley, which is interrupted by the crossbars at Aconcagua. Steinmann explains the gap in the coastal Cordillera between Taltal and Arica as the outcrop of a young collapse, in which an old continental mass similar to the Brazil-Guayana mass sank under the tides of the Southeast Pacific Ocean. Later, presumably in the late Quaternary, the present-day coastline was formed by further fault subsidence, the existence of which is indicated by the uplifted terraces and mussel beds in the middle or late Quaternary period. This is how the horst of the coastal Cordillera formed with a jump height of several kilometers seawards; today the edge of the sunken continental mass is characterized by the greatest depths of the Southeast Pacific Ocean with the long channel of the Lima (5868 m), Arequipa (6867 m), Atacama (7635 m) and Valparaiso trenches (5667 m). The floe now occupied by the Atacama Desert, part of the silted-up Mesozoic geosynclinal sea, has also undergone multiple vertical displacements together with parts of the Andes. This is indicated not only by certain sedimentary deposits but also by the terraces of the Huasco River, which continue along the coast as far as Caldera and Coquimbo. The town of Vallenar, which lies in the Huasco valley around 53 km from the coast, is surrounded by an amphitheater that rises in 5 terraces and has a diameter of 16-17 km compared to the other valley width of only 6-7 km.

The connection between our earthquake and local tectonics. The earthquake of November 10, 1922 proves to be an important support for the view that the Atacama, like the Great Chilean Longitudinal Valley, is a rift valley whose rupture margins run along the western Andes and the coastal Cordillera. The extent to which the earlier destructive earthquakes of the Atacama (10) can also be used to support this view cannot be assessed as long as we do not know from the distribution of the main areas of shaking in which region the epicenters were to be found and how the drop in earthquake strength towards the coast developed. Unfortunately, we still lack the observational material for such investigations.

We can state the following as an established fact: The earthquake of November 10, 1922 occurred on solid land at the western foot of the Andes between Vallenar and San Antonio, about 110 km from the sea. Taking into account the conditions that have been found in other, tectonically more precisely investigated earthquake areas, we must absolutely assume a rupture earthquake and reject the idea of a folding earthquake. This leads to the further assumption that the western slope of the Andes is formed by a fault, at least along the aforementioned section. This dislocation area became an earthquake focus because the growing tension on both sides exceeded the frictional resistance or the strength of the interlocking rock masses; a sudden, jerky vertical displacement of the clod edges, which caused the earthquake waves, had to restore the equilibrium of forces for some time. This process must have been connected with the release of very large amounts of energy in a flock that reached from very great depths close to the earth's surface, as can be seen from the comparison of the earthquake effect with the character classes of earthquakes established by Sieberg (11). Although the vertical displacement was so small that it apparently did not lead to visible and measurable earthquake dislocation, it is nevertheless a sign that the mountain-forming forces are alive in that region and are at work, through the summation of tiny individual movements in the long course of geological time periods, to finally bring about the enormous dislocations, often measuring in kilometers, which we are astonished to detect in the field.

From a theoretical point of view, the fundamental significance of our earthquake lies in the fact that on this occasion, for the first time, proof of the occurrence of large and global earthquakes on land in northern Chile, far from the sea coast, has probably been provided by flawless macro- and microseismic observations. Until now, experts had assumed that the major earthquakes in northern Chile originated beneath the deep-sea trenches. Especially in the case of those quakes that were accompanied by seismic waves, the submarine origin appeared to be beyond all doubt. This view has now also become obsolete, and the observational material we have received on the seismic waves, however incomplete it may be, offers us valuable insights into their origin.

IV. Course and effects of seismic waves.

Approximately ½ - ¾ hour after the earthquake - more exact times are not available - the disastrous movement of water masses began on the Chilean coast, which is known as seismic waves or the Japanese word tsunami and has become sadly famous. The water movement began everywhere with the water masses receding below the edge of the ebb. This process was repeated at least three times in front of the epicenter of the earthquake, with the second wave being the most powerful. Only in the north are the conditions different; from Caldera it is reported that the rebounding and flooding occurred more than twenty times, and in Chañaral the third wave was the worst. Near the origin of the seismic waves, their effects were devastating. The impact of the water masses destroyed buildings and roads, threw railroad trains off the tracks, hurled vehicles onto dry land and swept debris and numerous people out to sea as they retreated. At the mouth of the Elqui River, the seismic waves advanced 1½ km into the floodplain, as far as the vicinity of Compania Baja near La Serena. Thus, the sea tides completed the destruction caused by the earthquake, even surpassing it by far, especially noticeable at Coquimbo and Chañaral. Table III and the following details provide information on the effects of the seismic waves.

Tab. III. Effects of seismic waves.

Place	People killed	Destroyed buildings	The greatest advance of the wave		Waves-strong I-VI	Quake-strong I-XII
			Vertical	Horizontal		
Coquimbo	60	> 800	3.15 m	568 m	VI	VI
Beach off La Serena	?	almost all	5	750	VI	VIII
Carrizal Bajo	.	almost all	?	?	VI	VII
Chañaral	17	almost all	?	> 100	VI	VI-VII
Caldera	.	many	5	150	V	VII
Tongoi	.	numerous	?	?	V	VI
Coast off Illapel	.	11	?	?	IV	V-VI
Huasco	.	?	?	?	IV	IX
Antofagasta	.	some	5	125	IV	VI
Taltal	.	.	?	?	III	VI
Constitucion	.	.	4	?	III	V
Talcahuano-Concepcion	.	.	?	?	II	IV-V
Coronel	.	.	?	?	II	IV
Hilo (Hawaii)	.	.	?	?	III	.
Choshi (Japan)	.	.	?	?	I	.
Osaka (Japan)	.	.	?	?	I	.

Grade VI: Coquimbo was probably hit the hardest. Not only were the piers, warehouses and railroads destroyed, railroad carriages overturned and a barge thrown onto dry land, but the district of Baquedano with 800 houses and parts of the suburb of Victoria were completely washed away, with 60 fatalities. According to measurements by engineer Alejandro Varela Muñoz, the furthest point reached by the sea was 568 m from the beach and 3 m 15 cm high. A ship on the high seas at the height of Coquimbo did not perceive the seismic waves or the quake. On the beach that separates La Serena from the sea, the first wave washed weakly around the buildings at the harbor, but caused the first destruction in the harbor, after about 5 minutes there was another retreat to 150 m from the edge of the tide. This was followed by a 5 m high wave, which caused the greatest disturbance and swept away almost all the buildings on the flat, dune-covered beach up to 750 m inland. The seismic wave penetrated 1½ km into the floodplain of the Elqui River as far as the vicinity of Compania Baja. After a further 5 minutes, the sea retreated for the third time, only to return again weaker. At Carrizal Bajo, the railroad pier and the village were completely destroyed. Although it is not clear from the reports to what extent the earthquake was involved in the destruction, we can hardly go wrong if we attribute most of the damage to the seismic waves. In Chañaral, the first wave advanced calmly as far as the Merino Jarpa road, washing around a few houses. The second retreat was also rough, without agitating the sea, for more than 40 meters. The second surge advanced more strongly and with a greater mass of water, but also without waves or breakers, for 60 meters, flooding all the houses on the street. The third advance was the worst, a gigantic mountain of water washed away the entire low-lying part of the town, causing 17 deaths; the water remained at its highest level for 10 minutes.

V. Degree: During the first, slow retreat of the sea into Caldera, the hull of the armored ship "Blanco Encalada" was uncovered. Then there was a large swelling of the sea in the form of a high mountain of water, which slowly moved towards the harbor without breaking. It ebbed back and flooded forward more than twenty times. The pier, the customs buildings and the railroad workshops were submerged and damaged, entire railroad trains were washed away, but no human casualties were claimed. The greatest height the water reached on the beach was 5 meters, the greatest reach 150 meters. In Tongoi, the seismic waves destroyed the fishermen's houses on the beach and the railroad line.

IV. Grade: There is no harbor on the entire coast of the district of Illapel. The fiscal landing stage and 11 fishermen's huts were destroyed there. In Huasco, the damage was only minor; no details are given. At Antofagasta, the water began to recede rapidly, leaving the pier completely dry. Then the mass of water advanced about 125 meters above the normal level, swept away bathing huts, fishermen and workers' huts and threw light boats against buildings and rocks. The highest water level was 5 m above normal.

III degree: 8 fishing boats were lost in Taltal, as well as some in Constitucion; at the latter place the water level reached 4 meters.

II degree: At Talcahuano, the port of Concepcion, and at Coronel, only strong movement of the water was detected.

The seismic waves spread across the entire width of the Pacific Ocean. Thus, in the center of the North Pacific Basin, at Hilo on the island of Hawaii, 10500 km from the point of origin, numerous sampans and other boats were swept away, which corresponds to the III degree. This strikingly high strength, when compared with that in southern Chile, proves that the energy dissipation over the great depths of the ocean is much less than in the shallow coastal waters. Furthermore, we already know that the recording tide gauges or mareographs at Choshi and Osaka on the coast of Japan, at a distance of about 17000 km, have recorded the seismic waves. It is to be expected with certainty that in time even more mareograph stations in the Pacific Ocean area will publish news about corresponding recordings.

It is well known that seismic waves are transmission waves (12), i.e. transverse gravitational waves of a special kind. In contrast to ordinary water waves, these waves cause a quantity of water to travel from its source to another, often distant location. In this way, only very isolated wave crests are created, which travel alone in the direction of the impulse. This also distinguishes the transmission wave externally from the usual wind waves that only occur in swarms. This also distinguishes the transmission wave externally from ordinary wind waves, which only occur in swarms, while the speed of propagation is the same.

In general, at least for the open ocean, it can be assumed that the height and effects of seismic waves are most significant near the point of origin and decrease with increasing distance due to the internal friction of the water masses. However, as they approach the beach zone, the normal character changes as a result of the orographic conditions, namely both the slope of the beach and the course of the coast. This is because the approaching mass of water is forced to surge when the sea depth decreases and lateral compensation is impossible, as with the bora (13). As a result, the height of the waves, which on the high seas should usually remain below 1 m, can reach many meters on the beach due to upwelling. In the most violent event of this kind that we know of, the Krakatau surge in the Sunda Strait on August 27, 1883, 36 m were measured on Java's coast near Anjer, and even 40 m near Telok-Batang. On the other hand, protruding coastal forms, which stand in the way of the approaching water masses, offer protection to the coastal strips behind them due to the shadow effect. It is therefore a well-known fact of experience that seismic waves on coasts usually occur in very confined areas, so that often not even a trace of a wave can be noticed at a short distance from the scene of violent action. In our case, the conspicuous attenuation of the effects caused by the seismic waves in Huasco must be explained in this way. The distance of the buildings from the beach plays a further, coincidental role in the occurrence of building damage.

The effects of the seismic waves can best be overlooked if an empirical scale is established, just as for the earthquake strength, as Sieberg has done in Table IV.

Tab. IV. Scale for the effects of seismic waves.

I. Degree: Imperceptible. Only recorded by recording tide gauges.
II. Degree: Light. Just recognizable disturbance of the normal tidal current, no damage.
III. Degree: Moderate. Boats may be torn loose and washed away; makeshift or otherwise less resistant structures in the beach zone may be easily damaged.
IV. Degree: Severe. Flooding of less resistant structures in the beach zone, such as jetties, bathhouses, sheds, fishermen's huts, etc.; destruction of paths and railroad tracks; minor damage to solid structures of all kinds.
V. Degree: Destructive. Considerable damage to fixed piers, harbor facilities and solid buildings; larger ships are thrown to dry land, own trains are washed away.
VI. Degree: Catastrophe. Large-scale destruction of the most severe kind.

When interpreting the numerical values determined in this way, one must always bear in mind, with regard to our above explanations, that it can only be a matter of the apparent wave strength and not the true one, just as is the case with the indications of the degrees of strength for earthquakes. The true wave strengths could be determined by applying an orographic coefficient if one is able to study the effects on the spot or at least has large-scale coastal and harbor maps. Neither of these tools could be used in our study, so that we have to be content with an indicative consideration of more general aspects.

V. Origin and cause of the seismic waves.

The most reliable way to determine the approximate location of the source of a seismic wave is to determine the direction from which it originated at the various coastal locations. Good starting points for this are the observation of bent, broken, displaced and washed away objects, and knowledge of the strength of the waves is also important. For one thing, one can hardly be wrong in assuming that the coastal areas most affected were relatively closest to the point of origin. The shadow effect can also be taken into account.

In our case, unfortunately, almost all the information that could be used to determine the direction is missing, with the exception of the shadow effect. Careful examination of all factors that can be taken into account results in two separate starting points A and B with the approximate coordinates:

A:	$_1$ □= 71¾ ° W. Gr.	$_1$ = □29°S.
B:	$_2$ □= 71½ ° W. Gr.	$_2$ □= 26½ °S.

The first and, as we may well assume, primary starting point A lies on the steep drop to the deep sea, about 40 km off the coast halfway between Huasco and La Serena; the second B on the steep drop to the Atacama Trench between Caldera and Chañaral, about 80 km off the coast.

This surprising finding gains in probability if we critically examine the possibilities (14) for the origin of our seismic wave (Fig. 2). The fact that an explosion wave as a result of a submarine volcanic eruption is out of the question does not require any further explanation, especially since there are no observations to support such an assumption. We have also seen that our earthquake was a rupture earthquake with a continental focus. A submarine dislocation process, which one might first think of, cannot therefore be used to explain our seismic surge. Consequently, there is nothing left but the assumption that the earthquake tremors caused subaquatic landslides of huge masses of mud on submarine cliffs, which caused the water to be in turmoil over a wide area. In good agreement with this, our assumed starting point A, that of the main wave, is located on the very steep slope of the coastal section to which at least the IXth degree of earthquake strength is attributed. This is further supported by the fact that the water first retreated from the coast and only then flooded forward. There is also no doubt that the earthquake may have caused a particular subaqueous landslide on the steep slope of the Atacama Trench in B. It is even possible that the uplift could have been caused by the earthquake. It is even possible that the upheaval of the water masses in A could have triggered the landslide when it arrived in B. As there are no sufficiently precise time data, this question cannot be decided.

Fig. 2: The formation of seismic waves.

Literature.

1) For the geographical characteristics, the work by K. Martin: "Landeskunde von Chile". 2nd ed., Hamburg 1923, provided valuable clues.
The representation of the geological conditions given in our overview map Fig. 1 is mainly based on information from Berghaus, Bracke Busch, Brüggen, Domeyko, Loos, W. Penck, Sapper, Schiller, Sievers, Stappenbeck and Steinmann.
2) According to handwritten notes by J. Brüggen in Santiago de Chile.
3) Sieberg, Al: "Über die makroseismische Bestimmung der Erdbebenstärke. "G. Gerland's Beiträge zur Geophysik, vol. XI, p. 227, Leipzig 1912 - See also Tams, E., "Vereinheitlichung der Abschätzung von Erdbebenintensitäten." Petermanns Mitteilungen, 68th year, p. 245, Gotha 1922.
4) Reid, H. F.: "The Mechanics of the Earthquake." Vol. II of The Californian Earthquake of April 18, 1906. Report of the State Earthquake Investigation Commission, p. 55. Washington D.C. 1910. - Cf. 14) p. 109 and 162.
5) Summarized in Steinmann, G.: "Umfang, Beziehungen und Besonderheiten der andinen Geosynclinale." Geologische Rundschau, vol. XIV, p. 69, Berlin 1923, as well as numerous special studies.
6) Penck, W.: "Der Südrand der Puna de Atacama (NW-Argentina)." Vol. XXXVII of the Abhandlungen der math.-physik. Klasse der Sächsischen Akademie der Wissenschaften. Leipzig 1920.
- "On the form of Andean crustal movements and their relationship to sedimentation." Geologische Rundschau, vol. XIV, p. 301, Berlin 1924.
7) Philippi, R. A.: "Einige Worte über den unrichtigen Gebrauch des Wortes Cordillera in Chile." Journal of the Society for Geography in Berlin, vol. XXXIII, p. 393, Berlin 1898.
8) According to verbal communication.
9) Sueß, E.: "Das Antlitz der Erde", Vol. II, p. 665, Prague, Vienna, Leipzig 1888.
10) Montessus de Ballore, F. de: "Historia Sismica de los Andes Meridionales." Several volumes. Santiago de Chile 1910-1916.
11) Sieberg, A.: "Die Verbreitung der Erdbeben auf Grund neuerer makro- und mikroseismischer Beobachtungen und ihre Bedeutung für Fragen der Tektonik." Publications of the Main Station for Earthquake Research in Jena, No. 1, Jena 1922.
12) More details can be found in O. Krümmel: "Handbuch der Ozeanographie", 2nd ed. Vol. II, p. 23 ff. Stuttgart 1911 - Cf. also 14) p. 85 and 91.
13) On the theory of Bora see 0. Krümmel, p. 303, and M. P. Rudzki: "Physik der Erde", p. 426 ff. Leipzig 1911.
14) Sieberg, A.: "Geological, physical and applied earthquake science." With contributions by B. Gutenberg. Jena 1923.

Part II.

The processing of the instrumental records.

From B. Gutenberg.

VI The observation material.

The following processing of instrumental records of the earthquake is based on the original records (0), copies. of such (K), reprints (D) and station reports without illustration (B) from the stations listed in Tab. V (p. 30); see Pls. I-XVIII.

VII The hearth and the hearth time.

Unfortunately, there was not enough reliable information available from stations close to the focal point for the microseismic determination of the focal coordinates and the focal time; on the other hand, neither the information on P from distant stations nor that from S-P was sufficient, since the travel time curves for P - quite apart from the possibility that anomalous P waves (P_1 , P_2 ...) were present according to the investigations of A. Mohorovicic (2) - were still available above $\Delta = 100°$ as

Tab. V. List of stations and their herd distances.

Δ °	No.	Place		Δ °	No.	Place	
11.7	1	Villa Ortuzar	D	104.2	25	Durlach	O
12.2	2	La Paz	B	104.4	26	Ravensburg	O
25.6	3	Rio de Janeiro	B	104.6	27	Hohenheim	O
67.7	4	Washington	B	104.6	28	Heidelberg	O
73.4	5	Halifax	B	104.7	29	Bochum	O
74.0	6	Ottawa	B	104.9	30	Feldberg (Taunus)	O
88.5	7	San Fernando	K	104.9	31	Dyce	B
89.5	8	Coimbra	B	105.3	32	Innsbruck	O
90.4	9	Victoria B.C.	B	105.8	33	Munich	O
90.6	10	Cartuja	B	106.1	34	Sydney-Riverview	B
94.8	11	Algiers	B	106.3	35	Goettingen	K
95.3	12	Tortosa	D	107.0	36	Jena	O
96.6	13	Barcelona	K	107.2	37	Hamburg	K
99.7	14	Marseille	B	108.4	38	Lviv	B
100.3	15	Oxford	B	108.8	39	Vienna	O
100.6	16	Brussels	B	109.5	40	Athens	B
100.8	17	Parc St. Maur	B	110.1	41	Belgrade	B
100.9	18	Stoneyhurst	B	113.3	42	Upsala	K
102.4	19	West Bromwich	B	113.4	43	Königsberg	O
103.6	20	Zurich	O	153.7	44	Tokyo	D
103.7	21	Florence	B	162.1	45	Nagasaki	B
103.7	22	Strasbourg	B	162.7	46	Manila	B
103.7	23	De Bilt	K	169.5	47	Zi-ka-wei	D
104.2	24	Karlsruhe	O			Mareograms:	
				(151½)	Choshi		D
					Osaka		D

must be considered uncertain, while S above Δ = 82° is superimposed by other waves (S P_{44} S; see later). After eliminating stations whose data seemed inaccurate (e.g. due to obvious rounding off to certain fractions of minutes, cf. Rio de Janeiro) and those that were close together, 12 data remained as the most suitable for determining the origin: for P: nos. 1, 2, 4, 6, 9, 10, 11, 16 and for S-P: nos. 1, 4, 5, 6. 1, 4, 5, 6. The former provided 8 equations according to the method of L. Geiger (1), for the length λ and width φ of the hearth as well as for the hearth time 0, from the others 4 equations for φ and λ resulted analogously, of course with corresponding modification of the coefficients given by Geiger. The resolution of all 12 equations then yields for the hearth and hearth time (assuming a hearth depth of 25 km):

□ - 28.5°S. ± 0.4° m. F.
λ = 70.2°W.Gr. ± 0.7° m. F.
0 = $4^h\ 32^m\ 37^s$ ± 4s m. F. Greenwich Mean Time on 11.
= $23^h\ 32^m\ 37^s$ Chilean time on 10.

based on the transit time curves for P_n and S_n given by A. Mohorovicic (2). The mean errors determined as the calculation variable are increased by the uncertainty of the transit time curves and, above all, by the possibility that different types of P waves (P_1 , P_2 ...) were used as the basis for the calculation. The herd distances of the stations for Table V were calculated using the coordinates given.

It is clear from the records that several shocks, perhaps 3, took place at the focus, the second of which seems to have been somewhat stronger, and it is quite possible that the later ones originated from points further west than the first. This is supported by the fact that the interval between the shocks ("apparent" period of P?) in Villa Ortuzar and at the European stations was considerably higher at 24-

30 seconds than at the western stations Sydney, Tokyo, Zi-ka-wei, where normal period sizes of 4-12 seconds were recorded.

VII. The forerunners.

The deployment times were read off as far as possible, otherwise the times given in the reports were used; all values were entered in Table VI, in the prescribed columns, if the deployment could belong there in terms of time and appearance, otherwise under the heading "other deployments". Add 4h or 5h everywhere. The numbers of the stations are the same as in Tab. V. The differences against the transit time curves of B. Gutenberg (3) were then formed on the basis of the calculated hearth time and compiled in Tab. VII separately according to own readings and reports. Looking first at the column for P, the predominance of negative differences is noticeable, i.e. P was usually observed earlier than it should occur according to the calculation; on closer inspection, however, it becomes apparent that the particularly early onsets occurred mainly at stations with less sensitive pendulums whose records were not available, while at modern stations the onset of the earthquake appeared later, and the calculated and observed travel times usually differed less and below the mean error of the focal time calculation. One explanation for this initially strange-looking phenomenon may be based on the fact that at the time of the earthquake there was slight ground unrest almost everywhere, and some small wave of unrest was confused with the very weak P-waves at $\Delta > 90°$. Also in the submitted diagrams of low magnification instruments, P was marked several times at a point where even at high magnification only a few irregular waves could be found, as they had also been generated in other parts of the arc by the ground disturbance. This uncertainty disappears at high magnification. That P_1 or P_2 , according to A. Mohorovicic (2), perhaps occurred in De Bilt (-6°") or Strasbourg (-10°), perhaps also at other stations, is possible, but by no means certain. Differences can otherwise also be explained as uncertainties of the travel time curve, but above all as a result of the uncertainty of the focal time; even earlier onsets, P_3 , P_4 , P_5 , are unlikely to have occurred even with this exceptionally violent earthquake, unless such onsets are already assumed for the stations close to the focal point. Establishing this fact is probably the main result of the investigation of the travel times, as the earthquake cannot be considered for improving the travel time curve for P due to the uncertainty of the onset.

The following column shows the entry time of P′, i.e. the longitudinal wave that has passed through the core (4). For distances above 143°, the observed values agree with the theoretically found values within the error limits. For distances below 143°, where diffracted waves are involved (of which type has not yet been determined), this is also true, but there may be several groups of diffracted waves.

The beginning of PP generally appears to occur from $\Delta = 100°$ from 0.1 to 0.2 min. earlier than would be expected according to the transit time curve, but is usually disturbed and difficult to determine due to the superposition by P′ between $\Delta = 104°$ and 113°. This fact can be seen particularly clearly in De Bilt.

In a number of cases, PPP arrives roughly in line with the invoice or a little earlier.

The following wave S P_{44} S, which oscillates longitudinally in the core and transversely in the mantle (5), was usually regarded as "S", but cannot be S due to its flat transit time curve. Only in Vienna was this insert correctly interpreted. Calculated and observed entry times agree well with each other.

Tab. VI. Entry times of the precursors.

□°	No.	P	P′	PP	PPP	S P S_{44}	S	PS	SS	SSS	Further inserts (continued on p. 33)
		m s				.	m s				
11.7	1	35 21	.	.	.	.	37 36	.	.	.	.
12.2	2	35 40	.	.	.	.	?	.	.	.	.
25.6	3	38.0	.	.	.	.	42.6	.	.	.	.
67.7	4	43 37	.	m s	.	.	52 32	.	.	m	.
73.4	5	44 33	.	49 23	.	.	54 00	.	.	2.5	.
74.0	6	44 10	.	.	.	.	53 42	.	.	3	.
			.			m			m		m m m m
88.5	7	45 27	.	49.4	.	56.1	56.7	m	3.5	6.5	47.5 50.2 55.1 58.7
89.5	8	45 14	.	49 20	.	56.1	56 54	57.3	.	6.8	52.3 58.0 2.1
90.4	9	45 40	.	.	.	56.2	56 35	.	.	.	.
90.6	10	45 46	.	.	.	56.6	.	57.4	.	.	.
94.8	11	46 04	.	.	.	56.8	.	.	.	.	.
95.3	12	46 03	.	50.5	.	56.3	.	59.0	.	.	49.3 54.1 11.5
96.6	13	46 09	.	50 33	.	57.0	57 21	58.9	4.3	8.3	53.9 57.7 58.0 11.7
99.7	14	46 30	.	.	.	57.5	.	.	.	.	.
100.3	15	46 21	.	.	.	57.3	.	.	.	.	.
100.6	16	46 35	.	.	.	.	57 52	.	.	.	.
100.8	17	46 34	.	.	.	.	57 46	.	.	.	.
100.9	18	46 06	.	.	.	57.1	.	.	.	.	.
102.4	19	46 22	.	.	m	57.6	.	.	.	.	.
103.6	20	46 49	.	50.9	53.6	57.6	59.2	0.5	5.9	10.4	50.2 55.0 4.7
103.7	21	46 40	.	.	.	57.8	58.3	.	.	.	.
103.7	22	46 38	m s	.	m s	.	58.1	.	.	.	.
103.7	23	46 42	50 32	51 00	53 36	57.6	.	0.1	5.8	10.5	51.6 53.1 56.0 57.9*
104.2	24	46 54	50 25	51 01 51 20	53 47	57.5	59.1	0.9	6.0	9.9?	49.0 57.9 9.0 13.9
104.2	25	?	.	51.1	53.7	57.3	59.2	1.0	5.9	10.0?	48.3 49.7 51.5 52.2*
104.4	26	46 45	51.0	51.3	53 54	57.4	59 40	0.3	6.1	10.4	50.3 53.4 54.9 56.8*
104.6	27	46 48	50 44	51 19	53.6	57.6	59.2	0.4 u.1.0	6.4	10.3	50.0 53.0 55.9 56.9
104.6	28	46 48	50.8	51 15	53 45	57.6	.	0.6	6.1	.	58.1 3.6 5.5 6.7*
104.7	29	46 36?	50.7	51.2	.	57.5	59.2	0.5	6.2	10.3	49.0 51.5 52.7 55.6*
104.9	30	46 50	50.8	51.1	.	57.8	.	0.3	6.1	.	50.6 51.4 11.8 12.9
104.9	31	46 40	.	.	.	57.7	.	.	.	.	.
105.3	32	46 55	50.8	51.3	54.2	57.4	59.2	0.5	7.0	10.6	50.3 59.6 5.1
105.8	33	46 50	50.6	51 09	54.4	57.6	.	0.8	6.4	10.5	47.5 49.1 51.8 55.5*
106.1	34	45 12?	.	.	.	.	.	0.9	6.1	.	49^m 20^s 57^m 12^s 58^m 12^s
106.3	35	47 00	50.8	51.4	54.0	57.7	.	0.9	6.6	11.0	50.2 51.9 54.3 58.3*
107.0	36	47 02	50.5	51.5	54.1	58.0	.	0.9	6.5	11.0	49.3 51.1 53.2 55.9*
107.2	37	47 00	50.7	51.5	53.8	58.1	.	0.8	7.1	.	51.9 56.9 5.5 9.5
108.2	38	?	.	51.5	.	.	.	.	.	.	2.5
108.8	39	47 10	51.2	51.6	.	58.0	59.9	1.2	7.3	.	50.2 52.0 56.0 1.9*
109.5	40	?	51 11	51 45	.	.	.	1.6	7.6	.	.
110.1	41	47 26	.	.	.	57.8	59.1?	1.6	.	.	50.7 52.8 53.4 54.5
113.3	42	47 30	51.1	52 39	55.2	58.5	0.0	1.8	8.1	12.8	51.9 56.2 57.0 1.0*

Table VI (continued).

□°	No.	P	P′	PP	PPP	S P S_{44}	S	PS	SS	SSS	Further inserts (continued below)
			m s	m s	m	m	m	m	m	m	m m m m
113.4	43	?	.	52 12	55.0	58.5	0.8	2.0	8.1	.	48.6 52.7 58.8 59.8*
153.7	44	.	52 34	56.9	.	59.2?	8.1?	.	16.3	22.3	54.8 55.8 57.8 58.7*
162.1	45	.	52 44	.	.	.	.	.	.	.	.
162.7	46	.	52 42	.	.	.	.	.	.	.	.
169.5	47	.	53 04	58.1	.	0.5?	8.8?	.	18.9	.	53.8 54.0 55.1 56.5*

□°	No.	Further applications:	□°	No.	Further applications:
		m m s m m m m m			m s m m m m m m m
88.5	7	4.9 9.1	103.7	23	58 09 2.7 4.1 9.5 11.5 12.0 13.1
104.2	25	52.8 58 02 3.3 4.9 13.8 .	104.4	26	58 02 8.7 . . . . .
104.6	28	9.5 11.6 14 . . .	104.7	29	59.5 1.1 2.1 5.0 5.5 7.9 13.4
105.8	33	0.0 7.5 8.5 14 . .	106.3	35	59.8 9.2 10.3 12.8 . . .
107.0	36	4.9 6.8 10.0 14 . .	108.8	39	2.3(Z) 5.3 5.9 6.1 9.7 . .
113.3	42	2.0 4.2 5.5 11.5 15.0 .	113.4	43	2 21 4.6 6.0 10.6 . . .

153.7	44	1.8 3.3 4.5 7.0 9.9 12.3	169.5	47	57.7 59.3 0.5 1.5 2.1 3.5 4.6
				"	5.1 6.2 7.3 10.6 11.1 14.3 16.3

Table VII Differences between calculated and observed entry times the precursor. (Above according to own readings, below according to reports.)

□°	No.	Difference calculated - observed entry time at								
		P	P′	PP	PPP	S P S_{44}	S	PS	SS	SSS
		m s	m s	m s	m s	m	m s	m	m	m
11.7	1	- 6	.	.	.	.	- 4	.	.	.
88.5	7	- 5	.	+ 0.2	.	+0.1	+0.2	.	+1.0	+0.1
95.3	12	- 5	.	+ 0.4	.	-0.4	.	+0.4	.	.
96.6	13	- 6	.	+ 20	.	+0.1	- 13	+0.1	0.0	.
103.6	20	+ 1	.	- 0.2	- 0.2	+0.2	+0.4	+0.4	0.0	+0.1
103.7	23	- 6	- 9	- 7	- 14	0.0	.	0.0	-0.2	-0.1
104.2	24	+ 3	- 17	- 11	- 6	-0.2	+0.2	+0.7	0.0	.
104.2	25	.	.	- 0.1	- 0.2	0.0	+0.3	+0.8	-0.1	.
104.4	26	- 7	+ 0.3?	+ 0.1	0	-0.1	.	+0.1	0.0	-0.2
104.6	27	- 4		+ 4	- 0.3	-0.2	+0.2	+0.1	+0.3	-0.4
104.6	28	- 6	+ 0.1	0	- 12	-0.1	.	+0.3	0.0	.
104.7	29	- 17?	0.0	- 0.1	.	0.0	+0.2	+0.2	-0.4	.
104.9	30	- 4	0.0	- 0.2	.	+0.3	.	0.0	.	.
105.3	32	0	0.0	0.0	+ 0.1	-0.1	+0.1	+0.1	-0.3	.
105.8	33	- 6	- 0.2	- 15	+ 0.2	0.0	0.0	+0.3	-0.4	.
106.3	35	0	0.0	- 0.1	- 0.2	0.0	.	+0.3	-0.1	.
107.0	36	- 1	- 0.4	- 0.1	- 0.2	+0.3	.	+0.2	-0.3	.
107.2	37	- 3	- 0.2	- 0.1	-0.5	+0.4	.	0.0	.	.
108.8	39	- 2	+ 0.2	- 0.2	.	+0.2	+0.2	+0.1	+0.1	.
113.3	42	0	- 0.2	+ 13	+ 0.1	0.0	.	0.0	0.0	0.0
113.4	43	.	.	- 14	- 0.1	0.0	+0.4?	+0.2	0.0	.
153.7	44	.	-	+ 0.1	.	-0.6?	-0.2?	.	+0.1	+0.1
169.5	47	.	+	- 0.2	.	.	+0.1?	.	-0.1	.

□°	No	Diff. Ber. - observ. entry time at					□°	No	Diff. Ber. - observ. entry time at				
		P	PP	S P S_{44}	S	PS			P	PP	S P S_{44}	S	PS
		m s	m	m	m s	m			m s	m	m	m s	m
12.2	2	+ 6	.	.	.	.	100.8	17	- 1	.	.	- 25	.
25.3	3	-0.3		.	-0.1	.	100.9	18	- 30	.	-0.1	.	.
67.7	4	+ 4	.	.	0	.	102.4	19	- 21	.	+0.3	.	.
73.4	5	+ 16	+0.5?	.	+ 19	.	103.7	21	- 8	.	+0.3	.	.
74.0	6	0	.	.	+ 5	.	103.7	22	- 10	.	0.0	.	.
89.5	8	- 24	0.0	0.0	+ 21	-0.2	104.9	31	- 14	.	+0.2	.	.
90.4	9	- 3	.	0.0	- 7	.	106.1	34	-1 47?	.	.	.	+0.3
90.6	10	+ 2	.	+0.3	.	-0.3	108.4	38	.	.	.	.	.
94.8	11	- 2	.	+0.2	.	.	109.5	40	.	+ 6	.	.	+0.4
99.7	14	0	.	+0.4	.	.	110.1	41	+ 8	-27?	-0.1	.	+0.4
100.3	15	- 12	.	+0.1	.	.	162.1	45	.	-13	.	.	.
100.6	16	0	.	.	- 16	.	162.7	46	.	-15	.	.	.

S arrived in Europe soon after the previous wave; the entry times appear somewhat too late, perhaps because the beginning of S was lost in the rather strong movement; in part, S cannot be determined at all.

This applies to a greater extent to PS, which has the largest amplitudes in this diagram area.

SS seems to come a little too early, but its entry times and even more so those of SSS are very uncertain.

Several of the waves measured in the "Other inserts" section of Tab. VI probably originate from the wave S P P_{444} S (6), which arrives after S P_{44} S, or from PPS, which follows shortly after PS, or from P P P_{444} P, which is to be expected even later; the latter is particularly pronounced in some Z components. The waves PPPP and SSSS, which are reflected three times at the Earth's surface, also appear to be represented several times in this column. Finally, other deployment times are lined up in curves whose course and significance could not be determined with certainty.

The amplitudes cannot be used for a numerical analysis in the present case, as the overlapping due to the repeated shocks clouds the image. Particular attention should be drawn to the obvious decrease in P between $\Delta = 96.6°$ (Barcelona) and $\Delta = 103.7°$ (De Bilt), from where it can only be found at all at higher magnification. Table VIII shows the amplitude ratio PP:P, provided the stations had reliable instruments. Due to the circumstances mentioned, the data can only be regarded as rough values, but they are in excellent agreement with the previous results and indicate in particular that between 96.6% and 103.6° (on the basis of earlier investigations about 102°) is the beginning of the P-waves diffracted outside the Earth's core. The amplitudes of the other precursors, especially of S, cannot be utilized due to the complicated conditions.

Tab. VIII Ratio of the amplitudes of the once-reflected and the direct longitudinal precursors (PP:P).

No.	12	13	20	23	25	26	27	28	29	30	32
□°	95.3	96.6	103.6	103.7	104.2	104.4	104.6	104.6	104.7	104.9	105.3
PP:P	3.7	3	7	4½	10	5	7	12	9	8	5
No.	33	35	36	37	39	42	43	No.		44	47
□°	105.8	106.3	107.0	107.2	108.8	113.3	113.4	□°		153.7	169.5
PP:P	?	6	10	8	10	12	>15	PP:P′		1.9	3

As mentioned, the periods of the precursors in Europe were exceptionally high. Although there were also various normal periods, 4 and 12 seconds in particular, the diagrams showed main periods for all precursors, which were rarely less than 18 seconds and almost everywhere between 24 and 28 seconds, occasionally even higher, especially for the reflected transverse waves.

IX. The beginning of the surface and return waves.

General information. The investigation of surface waves during distant earthquakes has been neglected up to now. It was known that waves on the largest circle travel once directly from the source to the station (symbol "M"), but then also in the opposite direction via the opposite point (symbol "W_{II}"), and that both can reach the source after a further orbit of the earth after several hours and then return to the station for observation (as "W_{III}" or "W_{IV}") if the earthquake was strong enough. Recent theoretical investigations (10, 21) have shown that several groups of waves must orbit the earth at different speeds, one of them as pure shear waves with their surface speed V_Q, another special one as the Rayleigh waves already known earlier with theoretically about 8% less, still others of complicated construction with speeds considerably higher than V_Q, On the other hand, it follows (according to 16, 17, 18) that theoretically the surface wave speed on earth must increase with the period of the waves.

Examination of the recordings of the Atacama earthquake now shows beyond doubt for the first time that a group of surface waves existed before the Scheer and Rayleigh waves, which stood out particularly by high periods (over 1 minute), while in a second group, which probably represented a superposition of Scheer and Rayleigh waves, the wave period began at about ¾ minute and gradually decreased over certain particularly pronounced values (36-30 sec., approx. 24 sec., 22-16 sec.).

The following sections represent an initial attempt to identify the characteristics of the various types of surface waves and to search for their causes. Through the ongoing processing of foreign diagrams of the same earthquake, as well as records of the Tonga earthquake of June 26, 1917, and the Japan earthquakes of September 1 and 2, 1923

these investigations will then be continued.

The surface waves of the Atacama earthquake began at those stations that had instruments with sufficient magnification for very long waves, with periods of over 1 minute, which were then followed by waves with periods of ½-1 minute, which gradually merged into the maximum waves as the period continued to decrease. The

The beginning of the waves with periods of more than 1 minute, which we will briefly refer to as "L waves", was usually recognizable as a superimposition over the precursor movement (particularly pronounced in Zi-ka-wei, for example). A corresponding L_{II} wave (focus - counterpoint - station) was also usually very clear (e.g. report from Sydney "An anomalous wave train, not W_{II} "). The L_{III} and L_{IV} waves were no longer connected at all with the normal return waves; the deployment times were measured as those of unknown waves, and it was only from the transit times that it became clear beyond doubt that they were L_{III} or L_{IV} . All L-waves are recorded particularly clearly in Königsberg and Upsala, for example. Since the new L-waves are obviously very different from the other surface and return waves, they will be considered separately.

The periods T could only be measured approximately due to the mostly uncertain shape caused by overlapping. For L_I : $80 \leq T \leq 150$ sec; for L_{II} : $90 \leq T \leq 150$ sec; for L_{III} : $120 \leq T \leq 150$ sec; for L_{IV} : $130 \leq T \leq 150$ sec, i.e. mostly 2-2½ minutes.

The transit times. Table IX shows the observed entry times of the start of all L-waves. They were then used to calculate the corresponding mean velocities V_L for the various routes. From the average of the European stations, it appears that V_L decreased somewhat over time. However, this may only be due to the fact that at L_{II} and to a greater extent at L_{III} and L_{IV} the beginning of the waves was not sufficiently enlarged to be recognizable; perhaps the greater velocity of L_I is also related to the processes involved in its formation, On the other hand, it is clear that the velocity of the L waves under continents and oceans is not significantly different, as the comparison between the European and Pacific stations shows; but then, in contrast to the short-period surface waves, there are no differences in the various return waves. While L_I : has crossed about 5000 km of land and 6600 km of ocean (South America 3300 km, Atlantic 6600 km, the rest Spain and Central Europe); the L_{II} wave arriving in southern Germany has traveled almost 19 000 km in the bottom of the Pacific Ocean (in the case of northern Germany, the wave has traveled almost 19 000 km in the bottom of the Pacific Ocean). Ocean (and a small part of Australia in the case of the northern German stations) and only about half as far across the Eurasian continent. In the case of L_{II} and L_{IV} oceanic, especially Pacific, orbits therefore predominate much more than in the case of *LI*, and L_{III} . If there were a greater difference between the velocities in the continent and the ocean, the result would have to be similar to that which we will find with the short-period surface waves. Thus L had a constant velocity of 4.3 to 4.4 km/sec within the observation errors, regardless of the path traveled. The transit time curves previously given for eL require correction.

The decrease in L-waves can only be determined very roughly for the reasons mentioned several times. Table X shows the values of the "extinction coefficient" k for the 4 stations on whose recordings the L-waves are most clearly visible. The term "extinction coefficient" instead of ">absorption coefficient" was suggested by K. Uller (10), since in the case of complicated wave structures, such waves can be simulated during propagation even without absorption. Here, too, there is no noticeable difference between ocean and continent! The values are much lower than for the short maximum waves, as can be seen from the diagrams.

The azimuth of L could not be determined with certainty.

Tab. IX. Entry times and velocities of the L-waves.

□°	No.	Entry time from				V_L in km/sec. Calculated from						
		L_I 5^h min	L_{II} 6^h min	L_{III} 7^h min	L_{IV} 8^h min	O–L_I	O–L_{II}	O–L_{III}	O–L_{IV}	L – L_{IIII}	L – L_{IIIV}	L –L_{III}
88.5	7	10½	?	43	?	4.34	?	4.36	?	4.37	?	?
95.3	12	14	21	45	58 ?	4.28	4.50	4.38	4.36?	4.42	4.25	4.66
96.6	13	13	22	47	?	4.44	4.45	4.35	?	4.33	?	4.22
103.6	20	15	20 ?	?	?	4.53	4.42?	?	?	?	?	4.35
103.7	23	17	?	?	?	4.35	?	?	?	?	?	?
104.2	24	16	20	?	? ?	4.46	4.39	?	?	?	?	4.37
104.2	25	16	21	?	?	4.47	4.36	?	?	?	?	4.29
104.6	27	15½	17	?	?	4.53	4.51	?	?	?	?	4.52
104.6	28	16	19	?	?	4.58	4.43	?	?	?	?	4.42
104.7	29	15½	21	46	48½	4.44	4.35	4.46	4.45	4.43	4.232	4.23
104.9	30	16½	22	?	?	4.44	4.31	?	?	?	?	4.23
105.3	32	?	16	48	?	?	4.55	4.41	?	?	?	?
105.8	33	15	16	49	?	4.64	4.54	4.39	?	4.33	?	4.42
107.0	36	17 ?	18 ?	?	?	4.47?	4.46?	?	?	?	?	4.39
107.2	37	19	20 ?	49	53 ?	4.31	4.35?	4.40	4.36	4.35	4.36	4.39
108.8	39	17	18	51	?	4.53	4.40	4.38	?	4.33	?	4.29
113.3	42	19½	18	51	49	4.50	4.32	4.43	4.38	4.40	4.42	4.20
113.4	43	18	14	52	49	4.64	4.48	4.41	4.38	4.33	4.30	4.37
106.1	34	17½	17½	?	?	4.37	4.48	?	?	?	?	?
153.7	44	34½?	?	?	?	4.70?	?	?	?	?	?	?
169.5	47	42	53*	13*	24	4.52	4.39	4.45	4.40	4.42	4.42	?
Medium 7-43		-	-	-	-	4.46	4.43	4.40	4.38	4.37	4.31	4.36

The minute numbers marked with * refer to the previous or following hour.

Tab. X. Extinction coefficient of the L-waves.

□°	No.	Extinction coefficient k in units of the 5th decimal point calculated from					
		L_I and L_{III}	L_{II} and L_{IV}	L_I and L_{II}	L_{III} and L_{IV}	L_{II} and L_{III}	L_I and L_{IV}
113.3	42	9	15	9	19	9	13
113.4	43	12	12	9	9	13	11
106.1	34	?	?	17	?	?	?
169.5	47	10	12	?	?	10	11

X. The maximum and return waves.

The earlier results. Taking into account the influence of the traversed . areas, in particular the ocean and continent, three major studies have been published since then:

Author	Designation the wave	Material	V_{kont} km/sec ($k_{kont.}$ 10)^5	V_{ozean} km/sec ($k_{ozean.}$ 10)^5
E. Tams (7°	"Surface waves" (El)	Many quakes (reports)	3.801 ± 0.029 m.F.	3.897 ± 0.028 m.F.
S. W. Visser (9)	"Long waves" (appearance of L)	Many quakes (reports)	3.70	3.78
G. Angenheister (8)	"L"	Two quakes	3.87 u. 4.09 (k = 9-17)	4.68 u. 4.58 (k = 32-37)

These authors probably used partly the "L" waves discussed since then, partly the beginning of the ordinary surface waves, since the reports simply indicate the first appearance of surface waves, sometimes also of eSSS, as S. W. Visser correctly notes. The results will therefore represent a superposition of the laws applicable to L and to the later M waves. With regard to Angenheister's results on absorption, it should be noted that he was unable to take into account the influence of the background (see below). The study by E. Tams is of particular significance in that, based on the different nature of the marine and continental subsoil, he expected the differences in propagation speed in both and was able to confirm them more precisely. E. Rosenthal (11) and 0. Meißner (12) had previously pointed out the different propagation of surface waves in different areas.

The time of onset of the normal maximum (M) and return waves (W_{II} , W_{III} , W_{IV}) is characterized by the onset of waves with periods of approx. ¾ min, but can rarely be determined. In particular, eW_{II} was always superimposed and eW_{IV} too weak. A first maximum with periods of between 30 and 36 seconds immediately afterwards, which we will refer to as "M_{30} ", usually stands out somewhat better. The first conspicuous maximum then generally followed with periods of approx. 24 seconds ("M_{24} "), while at the main maximum ("M") the periods were further reduced. All these points in time were measured, an accuracy similar to L could of course be achieved here. The speed of these waves was then calculated for Table XII on the basis of these measurements.

The amplitudes of the main maxima and the extinction factors are summarized in Table WI. The absolute values show partly large differences, which are partly due to a lack of accuracy of the instrumental constants or insufficient knowledge of the magnification of waves with large periods, but partly are a consequence of the different background factors according to the investigations of H. Reich (13) and can falsify the calculation of the extinction coefficient k when using the amplitudes of different stations. We therefore want to calculate k from the amplitudes of the return waves (14). First of all, M and W_{III} or W_{II} and W_{IV} provide the value k = 0.00022 for the largest circle Herd - South America - Atlantic - Eurasia - Pacific Herd, i.e. not the arithmetic mean! The values calculated from M and W_{II} or W_{III} and W_{IV} for the European stations are equal to each other according to the theory, namely with k = 0.00032 considerably higher; this fact is so pronounced at all stations that there can be no doubt. In connection with the low value of k = 0.00015 in Sydney, it follows from this that the extinction was greatest when passing through the Pacific Ocean. W_{II} and W_{III} yield k = 0.00013 for the section Herd-South America-Atlantic-Europe, analogous to M and W_{IV} : k = 0.00023 for Pacific + Eurasia. As the value of k in the Pacific is considerably lower than this figure, the value for Eurasia is much lower. The following extinction factors are obtained for the maximum waves of the Atacama earthquake if the waves run in an east-west direction or vice versa: For the Atlantic + South America and also in Eurasia k is below 0.0002, for waves through the Pacific 4 k is above 0.0003. To explain this phenomenon only by large absorption in the Pacific is premature, since in addition to the wave structure (cf. p. 39/40) refraction and reflections on deep discontinuity surfaces (continental blocks!) are likely to play a major role. The results that can be expected from further investigations may lead to important conclusions about tectonics and the formation of the continents.

Tab. XI Extinction coefficient and maximum amplitudes of surface waves

□°	No.	Absorbance factor k in units of the 5th decimal point calculated from						Maximum amplitude in μ at			
		M and W_{III}	W_{II} and W_{IV}	M and W_{II}	W_{III} and W_{IV}	M and W_{IV}	W_{II} And W_{III}	M	W_{II}	W_{III}	W_{IV}
95.3	12	19	.	26	.	.	12	Approx.	Approx.	Approx.	Approx.
96.6	13	16	19	22	28	20	12	1800	150	55	3
103.6	20	22	21	39	37	.	10	.	80	25	.
104.2	24	20	.	32	.	.	11	.	.	.	.
104.2	25	18	18	27	28	21	11	.	.	.	.
104.4	26	20	.	32	.	.	11	1600	75	32	.
104.6	27	20	.	28	.	.	14	.	.	.	.
104.6	28	.	.	34	.	.	.	.	.	.	.
104.7	29	21	.	28	.	.	23	1000	85	10	.
104.9	30	20	.	38	.	.	24	.	.	.	.
105.3	32	.	.	42	.	.	.	1200	35	.	.
105.8	33	.	.	29	.	.	.	1750	125	.	.
107.0	36	39	29	44	32	25	9	1400	35	13	1
107.2	37	18	20	26	29	22	13	1700	230	46	3
108.8	39	21	.	37	.	.	11	.	.	.	.
113.3	42	22	24	35	39	27	13	2200	115	20	1
113.4	43	18	.	26	.	.	14	.	.	.	.
106.1	34	22	.	15	.	.	25	.	.	.	.
153.7	44	21	.	.	.	.	.	.	.	.	.
169.5	47	17	.	.	.	.	.	.	.	.	.
Medium 12-43			22	32	32	23	13	-	-	-	-

The speed of the surface waves was compiled in Table XII. From the first surface waves with periods between 30 and 36 seconds (M_{30}), the result for South America - Atlantic - Europe is: V = 3.85 km/sec; for the Pacific (No. 44, 47) it appears to be a little higher. The onset of these waves is of course somewhat faster but, as mentioned, could not be determined with certainty. The "first maxima with periods around 24 sec. (M_{24}) resulted in V = 3.52 km/sec for South America + Atlantic, for the Pacific (No. 34-47) V = 3.76 km/sec, i.e. considerably more. For the main maximum M the differences are probably even greater (3.21 km/sec or for No. 44: 3.73 km/sec).

These results are excellently confirmed by the return waves. (At W_{III} and W_{IV} the different maxima are almost the same everywhere, so that no distinction was made between the 1st and main maximum. Surface waves with periods longer than 24 seconds were already no longer reliably detectable in W_{II}. From M- W_{III} and W_{II} -W_{IV}, V_M =3.7 km/sec results consistently for the entire circle Herd - Europe - Pacific - Herd and waves with periods of 10-24 sec, whereas the values for V_M, which result from O-M and O-W_{III}, are smaller at the European stations,

Tab. XII. Velocity of surface waves

□°	No.	Velocity VM of the surface waves in km/sec calculated from										
		O-M_{30}	O-M_{24}	O-M	O-$W_{II,24}$	O-W_{II}	O-W_{III}	O-W_{IV}	M -W_{24III}	W - $W_{II,24IV}$	M-$W_{II,24}$	W - $W_{II,24III}$
88.5	7	.	3.97	.	.	.	3.65	.	3.58	.	.	.
95.3	12	.	3.91	3.14	4.17	4.17	3.68	.	3.62	.	4.33	3.18
96.6	13	3.66	3.37	2.99	4.03	4.03	3.69	3.91	3.79	3.82	4.54	3.32
103.6	20	4.17	3.47	3.09	3.69	3.59	3.64	.	3.70	.	3.85	3.61
103.7	23	3.62	3.26	2.91	4.12	4.12	.	.	.	.	5.04	.
104.2	24	4.06	3.78	2.99	3.80	3.55	3.70	.	3.68	.	3.81	3.61
104.2	25	4.14	3.78	3.29	3.67	3.67	3.69	3.74	3.64	3.79	3.67	3.71
104.4	26	3.75	3.64	3.35	4.24	4.23	3.70	.	3.72	.	4.81	3.22
104.6	27	3.56	3.28	3.10	4.24	4.24	3.66	.	3.79	.	5.47	3.15
104.6	28	.	3.36	3.36	4.09	4.09	.	.	.	.	4.75	.
104.7	29	3.84	3.79	2.86	3.89	3.89	3.63	.	3.58	.	3.97	3.35
104.9	30	3.75	3.35	3.35	.	4.20	3.69	.	3.81	.	.	.
105.3	32	.	3.28	3.28	.	.	.	.	.	.	.	.
105.8	33	3.84	3.35	3.24	3.65	3.65	.	.	.	.	3.89	.
107.0	36	3.83	3.41	3.17	.	3.55	3.64	3.63	3.74	.	.	.
107.2	37	.	3.36	3.29	3.79	3.64	3.69	3.74	3.81	3.70	4.42	3.59
108.8	39	4.07	3.30	3.26	3.56	3.56	3.66	.	3.79	.	3.81	3.79
113.3	42	3.92	3.56	3.53	3.86	3.86	3.66	3.65	3.69	3.52	4.19	3.46
113.4	43	3.79	3.56	3.53	3.63	3.31	3.68	.	3.72	.	3.71	3.71
106.1	34	.	3.81	.	3.65	.	3.73	.	3.73	.	3.81	3.89
153.7	44	4.04	3.81	3.73	.	.	.	.	.	.	.	.
162.1	45	.	3.77	.	.	.	.	.	.	.	.	.
162.7	46	.	3.75	.	.	.	.	.	.	.	.	.
169.5	47	3.81	3.65	.	.	.	3.55	.	3.50	.	.	.
Medium	7-43	3.85	3.52	3.21	3.90	3.82	3.67	3.73	3.71	3.71	4.28	3.43

the values calculated from 0-W_{II} and 0-W_{IV} are greater. The values calculated from M-W_{II} and W_{II} -W_{III} confirm the result. We therefore find a speed of about 3.8 km/sec for the surface waves of the Atacama earthquake with periods of 16 to 24 seconds in the Pacific and about 3.5 km/sec in South America + Atlantic, i.e. considerably lower. For Eurasia, the processing of the Japan earthquakes promises more precise results. For the initial surface waves with higher periods, the differences seem to be smaller according to the results of Tams, but considerably larger for the main maxima. As with the extinction factors, we find considerable differences here, which we must attribute to the different structure of the earth's crust.

The type of oscillation of the maximum waves was difficult to determine. Apparently, longitudinal and transverse waves were superimposed right from the start; the vertical movement, which began quite strongly at about the same time as the horizontal movement, also indicates that waves similar to Rayleigh waves appear to have occurred right from the start. The pure transverse waves at the beginning of the surface waves, which are otherwise often observed in earthquakes, were not pronounced anywhere, and Innsbruck, where the components were in the direction of the focus and perpendicular to it, only registered transverse vibrations to a greater extent some time after the beginning.

The periods of the main waves and the trailing waves are shown in the following overview (particularly frequent values are printed in bold). Periods of 12 seconds were completely missing, differences between European and Pacific stations (American stations were missing!) were not detectable (20).

Period for	M	W_{II}	W_{III}	W_{IV}
Main waves:	First 36-30, then 26-22, then 22-19-16-15	24-18-16-14	24-20-16-15	16

Followers:	20-16½-16-13	20-18-16-14	20-18-16-15	?

XI. Attempts to explain the observations of surface waves.

According to the latest investigations (15), at least parts of the Earth - details have initially only been determined for Europe - have a cortical layer in which the density ρ increases from about 2¾ to 3, the modulus of rigidity μ from about 3½ × 10^{-11} to 4½ × 10^{-11} (CGS), and then jumps to about 3½ or 6½ × 10^{-11} at the lower limit at a depth of d = 55-60 km. Love (16) has now shown that in the case of such a homogeneous rind layer, surface waves arise whose speed for transverse waves is between β_0 for short waves and β_a for very long waves, depending on the wavelength. (β_0 = speed of the transverse waves in the bark, β_a below; $\beta_0 < \beta_a$). In Europe, β_0 = approx. 3½, β_a = approx. 4.3 km/sec. Based on the above values for the surface and just below the depth d, Love's theory yields the following related values between the period T_Q of the surface waves and their velocity V_Q (for transverse waves):

T_Q	01020405075115230				∞	sec				
V_Q	3.5	3,5	3,6	3,8	3,9	4,1	4,2	4,3	4.	3km/sec

The results for the Herd-Atlantic-Europe arc in Tables IX and XI correspond quite well to these values:

T_M	approx. 24 (M_{24})	approx. 33 (M)$_{30}$	approx. 150 (L)	sec
V_M	3.5	3.85	4.4km/sec	

However, Love's theory may not be applicable to the ocean, since the existence of the discontinuity layer at a depth of 60 km is not certain there, and the sima on which the continental blocks rest may extend to the surface. Then - just as within the rind layer - the investigations of E. Meißner (17) would have to be taken as a basis, 'who has established that even with a continuous increase in ρ and μ [incidentally also (18) with the resonance of an inert rind layer] long surface waves must run faster than short ones. Of course, this results in different values than with Love's theory. By combining both - different for continent and ocean - the differences between L- and W-waves can be explained. However, the gap and the lack of correlation between the two in the case of the W_{III} and W_{IV} waves would then be strange. Another possible explanation should therefore be mentioned. K. Uller (10) has shown that in surface plane waves, in addition to Rayleigh and transverse waves, line-polarized surface waves also propagate, the speed of which depends on the ratio of the longitudinal to the transverse component and can be considerably higher than the speed of the transverse waves. Perhaps the L-waves are of this type. A decision on the probability of these different possibilities cannot be made on the basis of this one quake. Given the relatively considerable thickness of the layer oscillating in the L-waves, the elasticity conditions of the deeper layers are primarily decisive for these waves, whereas the structure of the surface layers plays a greater role in the short-period waves. With Love's theory, this can be easily calculated. For very long waves, $V_Q = \beta_a$, while for shorter waves V_Q increasingly approaches the changing speed β_0 , which is different for the continents and oceans. The same applies to Meissner's theory. This explains our result that the shorter the wave periods, the greater the differences between the behavior of the surface waves in the different parts of the earth, and that there are no noticeable differences at all for very long waves. As a result of the change in elasticity constants, especially at the transition from ocean to land, the relationships become particularly complicated. With certain theoretical restrictions, J. H. Jeans (21) recently arrived at qualitatively similar results to those of Uller. Jeans then also assumed that even after several orbits around the earth, the energy of the surface waves returning to the source at the same time was so great that they could trigger further earthquakes there. However, this is extremely unlikely, since on the one hand the waves travel at different speeds on the various largest circles, and on the other hand, as already mentioned, sudden changes in the elasticity constants (edge of the continental blocks!) must result in reflections in more or less different directions, i.e. the waves generally do not reach the source again. This weakens the continuing wave, while the reflected energy gives rise to new surface wave systems: Refractions on the mostly curved and kinked surfaces cause the amplitudes to be different in different directions. If a surface wave even runs in the direction of a vertical discontinuity surface, for example along a Pacific continental margin, special irregularities can arise. If the elasticity constants in an area change gradually, corresponding beam curvatures occur. Even in these cases, the surface waves only return to the source in exceptional cases, so that they can hardly be considered as a triggering cause for aftershocks.

Numerous interesting questions remain unanswered: Under what circumstances do the long L-waves occur? Are they related to the depth of the source? the location of the source? (edge of the continental blocks?) the energy of the earthquake? its type of triggering? Only the systematic investigation of many earthquakes can shed light on all the problems discussed here, which have since been greatly neglected. A more intensive cooperation between seismophysics and geology is particularly promising here.

XII. The records of the seismic waves.

The earthquake caused seismic waves, which Sieberg reported on in the first part (p. 27) at a distance of about 40 or 80 km from the coast, and which were probably triggered at about 4^h 33^m . According to the observations, a considerable fraction of an hour may have elapsed before they reached the coast itself, as the speed v of the water waves of great length is relatively small near the coast due to the shallower sea depth, $V^2 = g.h$, where $g = 9.8$, h = sea depth, all expressed in m, sec. According to S. Nakamura (19), they reached the Japanese station Choshi, located on the open Pacific Ocean, at 3 0^{hm} the following day. According to this, the first tidal waves in the Pacific Ocean between Chile and Japan had a speed of about 208 m per second. Since their period was about 30 minutes, this results in a wave length of about 375 km, corresponding to a mean sea depth of about 4000 m, which corresponds quite well with the actual conditions. According to Nakamura, the maximum amplitude of the waves in Choshi was 22.7 cm; they set the tide gauges in Osaka in motion for about 24 hours and in Choshi for several days.

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Abbreviation: Th. d. E. = B. Gutenberg: "Theorie der Erdbebenwellen..." in "Geologische, physikalische und angewandte Erdbebenkunde" by A. Sieberg, Verlag Gustav Fischer, Jena, 1923, pp. 283-372.

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