EARTHQUAKE OF FEBRUARY 18, 1911

By Otto Klotz

There appeared recently a short paper by Prince Galitzin in *Comptes Rendus,* tome 160, p. 810, on the above earthquake which is of great interest to seismologists, and hence deserves a place in a seismological journal, which is my reason for offering the following translation together with some notes.

Earthquake of February 18, 1911.

(Galitzin, *Comptes Rendus,* **160**, 810.)

On February 18, 1911, a very violent earthquake took place in the Pamirs, and was generally registered at seismological stations. The seismograms obtained offer nothing in particular, and as more than four years have elapsed since then, this earthquake would certainly have been forgotten, if it had not been known later that on the same day and at the same hour an immense mountain slide occurred at Sarez in the Pamirs, which fell into the valley of the Mourgaf river and transformed it into a lake. Two years later Lieutenant Colonel Spilko of the Russian army visited Sarez and there studied in detail this remarkable slide, of which he gives a detailed map. He shows that on the 18th of February at $11^h\ 15^m$ in the evening Sarez was visited by a very severe earthquake, of intensity VIII, whereby 180 persons lost their lives in the district of Oroshor. Spilko gives as co-ordinates for the slide,

$$\varphi = 38^\circ\ 16'\ \text{N}, \qquad \lambda = 72^\circ\ 34'\ \text{E, Greenwich.}$$

This point is 3800 km. from the seismological station at Pulkovo. The Pulkovo seismogram gives for the beginning of the first phase of this earthquake the time,

$$P = 18^h\ 47^m\ 45^s\ \text{G. M. T.}$$

In applying the time required for the P waves to reach Pulkovo, $7^m\ 02^s$, we find the time of the quake to be $O = 23^h\ 17^m\ 55^s$, mean time Tashkent Observatory, which agrees with the time given by Spilko.

Let us now compare the distances Δ from the place of the slide to the different seismological stations with the epicentral distances Δ' deduced from the difference of times of arrival of the P and S waves.

Stations	Δ km.	Δ' km.	$\Delta-\Delta'$ km.
Tashkent	440	480	— 40
Baku	1960	1910	+ 50
Tiflis	2390	2430	— 40
Pulkovo	3800	3690	+110

The interagreement of Δ and Δ' may be considered very satisfactory. There can be no doubt then that the place of the slide and the epicenter fall together.

From the map or plan of Spilko, Mr. Weber, of the Russian geological survey, has determined the approximate value of the mountain mass which fell, as well as of the lowering, H, of its center of gravity. Accurate measures are of course not possible, yet one can fix approximately the order of magnitude of these quantities. Weber finds for M the enormous value of 7 to 10 billions of tonnes (milliard de tonnes). The limits of H are put at 300 to 600 meters.

These data enable us to determine two limits for the total energy, E, released by the slide in question. Putting g for acceleration, we have

$$E = MgH \quad . \quad . \quad . \quad . \quad (1)$$

Introducing into this expression the preceding values, and expressing the result in absolute C. G. S. units, we find the two following values,

$$E = 2.1 \times 10^{23} \text{ ergs.}$$
$$E = 6.q \times 10^{23} \text{ ergs.}$$

This is certainly an enormous quantity.

One can now put the following question: Was the slide at Sarez the result or the cause of the earthquake recorded at so many distant stations?

To answer this question let us try to evaluate the energy released at the epicenter from the data obtained at the Pulkovo seismological station, which at the time was provided with aperiodic seismographs very sensitive to galvanometric registration. The energy E, freed at the epicenter, propagates itself towards the interior and along the surface of the earth. The analysis of the seismograms of distant stations shows that the energy manifested itself almost exclusively in the surface or long waves. Taking into account the damping or absorption of the seismic movement, we obtain for the total energy E, traversing unit surface at an epicentral distance Δ during the whole time of appreciable movement of the earth, the following expression:

$$E_1 = \frac{E}{2\pi\Delta^2} e^{-k\Delta} \quad . \quad . \quad . \quad . \quad (2)$$

where k is the coefficient of absorption. Calling ϵ the quantity of energy traversing unit surface at the observation station during unit time, V the velocity of the long waves, ρ the density of the superficial crust of the earth, and v_m^2 the mean of the squares of the velocity of a particle of earth during a complete oscillation, we have

$$\epsilon = \tfrac{1}{2} V\rho v_m^2. \quad . \quad . \quad . \quad . \quad (3)$$

Let a now be the amplitude of an earth particle and T the period of the corresponding seismic wave; we can then put

$$v_m^2 = \tfrac{1}{2}\left(\frac{2\pi a}{T}\right)^2 \quad . \quad . \quad . \quad . \quad (4)$$

a and T being in general variables; but, for a certain duration of time t, we may take the mean values as constant. Hence from equations (3) and (4) we may write

$$E_1 = \pi^2 V\rho\Sigma\left(\frac{a}{T}\right)^2 t. \quad . \quad . \quad . \quad (5)$$

The summation of Σ should be extended to the whole of the principal phase. If we designate the three components of the true movement of the earth particle by x_N, x_E, x_Z,

$$\text{then} \quad a = \sqrt{x_N^2 + x_E^2 + x_Z^2}.$$

A detailed analysis of the seismogram could certainly give us the value of a, but for our purpose we may proceed in a more simple manner.

As the plane of oscillation of an earth particle changes constantly in direction, we may put for the mean $x_E^2 = x_N^2$. Furthermore, the theory of surface waves given by Lord Rayleigh and H. Lamb, shows that the vertical component of the movement of an earth particle should be in a constant ratio to the corresponding horizontal component. This ratio is according to theory 1.47, but the observations at

Pulkovo show that it is somewhat less, being 1.2. Hence the following relation is readily deduced:

$$a^2 = 4.88 x_N^2.$$

Combining equations (2) and (5), we have the total energy released at the epicenter,

$$E = 9.76\pi^3 \Delta^2 e^{k\Delta} V \rho \Sigma \left(\frac{x_N}{T}\right)^2 t. \quad . \quad . \quad . \quad (6)$$

The reading of the seismogram at Pulkovo of this earthquake has given the following mean values of x_N and T for the different intervals of time t:

x_N	T	t
μ	s	min.
225	15	14
60	12	16
25	13	30
10	15	25

Hence

$$\Sigma \left(\frac{x_N}{T}\right)^2 t = .00221 \text{ C.G.S.}$$

Furthermore

$$\rho = 2.8, \quad V = 3.5 \frac{\text{km.}}{\text{sec.}}, \quad \text{and} \quad \Delta = 3800 \text{ km.}$$

Respecting the value of k, one may put it equal to .0004, if Δ is expressed in kilometers, for this earthquake, based on the observations at Pulkovo. Introducing these values into (6), and expressing the result in absolute units, we have

$$E = 4.3 \times 10^{23} \text{ C.G.S.}$$

Comparing this value deduced from the Pulkovo observations with the two limiting values of E found above, viz. $(2.1 \text{ to } 6.0) \times 10^{23}$ C.G.S., we see that they are not only of the same order of magnitude, but approach each other numerically.

This unexpected result leads us then to the following conclusion: Whatever may have been the cause of the slide at Sarez, we may claim with a great probability of truth that the slide was not the consequence, but the cause of the earthquake of February 18th, which was registered at many distant earthquake stations. This earthquake presents to us an exceedingly interesting case, and unique as far as my knowledge is concerned, where we have directly the value of the energy released at the epicenter, which besides coincides here with the hypocenter itself.

This is the end of the translation; and now a word about Galitzin's formulae, before discussing the Ottawa seismogram of February 18, 1911.

It will probably serve a good purpose if we express the six equations in dimensions of mass, length and time, thereby showing too the inter-relationship of them. In the reduction we shall express each term first by its own dimension.

(1) $E = MgH = MLT^{-2}L = ML^2T^{-2}$, a fundamental expression in dimensions for kinetic energy.

(2) $E_1 = \frac{E}{2\pi\Delta^2}e^{-k\Delta} = ML^2T^{-2}L^{-2} = MT^{-2}$, energy per unit area.

(3) $\epsilon = \frac{1}{2}V\rho v_m^2 = LT^{-1}ML^{-3}L^2T^{-2} = MT^{-3}$, i.e., $= \frac{E_1}{T}$, or MT^{-3}.

The energy for unit area for unit time equals the whole energy for unit area divided by the time.

(4) $v_m^2 = \frac{1}{2}\left(\frac{2\pi a}{T}\right)^2 = L^2T^{-2}$.

(5) $E_1 = \pi^2 V\rho\Sigma\left(\frac{a}{T}\right)^2 t = LT^{-1}ML^{-3}L^2T^{-2} = MT^{-2}$, as in (2),

(6) $E = 9.76\pi^3\Delta^2 e^{k\Delta}\,V\rho\Sigma\left(\frac{x_N}{T}\right)^2 t = L^2LT^{-1}ML^{-3}L^2T^{-2}T = ML^2T^{-2}$, as in (1).

The denominator in (2) is the area of the hemisphere of radius Δ.

In equation (3), v_m^2 must be distinguished from $v^2 = \left(\frac{2\pi a}{T}\right)^2$; the latter v pertains to the uniform velocity, while v_m^2 represents the mean of the squares of the velocity in the harmonic motion. It is the mean value of $\sin^2\varphi$, for all values of φ, the angle of phase, from $\varphi = 0$ to $\varphi = 2\pi$. This mean value is equal to $\frac{1}{2\pi}\int_0^{2\pi}\sin^2\varphi\, d\varphi$. The indefinite integral $\int \sin^2 \varphi \, d\varphi = \frac{1}{2}\varphi - \frac{1}{4} \sin 2\varphi + C$; therefore $\frac{1}{2\pi}\int_0^{2\pi} \sin^2 \varphi \, d\varphi = \frac{1}{2}$, *i. e.*, the mean value of $\sin^2 \varphi$ for a complete oscillation is ½. The e in equations (2) and (6) is the base of Napierian logarithms. Equation (5) is obvious. The numerical coefficient 9.76 in equation (6) is obtained thus: as explained, $x_N{}^2$ is taken equal to $x_E{}^2$ and theoretically $x_Z = 1.47 x_H$ (Poisson's ratio being taken at ¼), where x_H is the horizontal component and equal to $\sqrt{x_N{}^2 + x_E{}^2}$; hence $a = \sqrt{2x_N{}^2 + (1.47\sqrt{2x_N})^2}$. Galitzin uses 1.2 instead of 1.47, therefore his $a^2 = 4.88 x_N{}^2$, and the coefficient 9.76 follows.

In the summation of $\Sigma \left(\frac{x_N}{T}\right)^2 t$, all the terms must be expressed in centimeters and seconds respectively. The energy evaluated pertains only to the long waves, which as Galitzin states show almost exclusively the energy. Whatever the energy shown by the longitudinal and transverse waves is, it is small compared with the former. From our Ottawa seismogram it is about one-thirtieth of that of the long waves, so that the deduced energy should be increased by that amount.

The density 2.8 answers for the immediate surface, while for Wiechert's crust or shell the density is 3.2. As a matter of fact, we do not know to what depth the long waves are involved.

Now let us look at our record (bulletin issued) for that day, and we find a distant earthquake recorded giving

$$P = 19^h\, 04^m\, 44^s, \quad L = 19^h\, 23.7^m, \quad M = 19^h\, 35.5^m$$

the mean of the N and S components. From Galitzin's data we find the time of the quake $= O = 18^h\, 40^m\, 43^s$ G.M.T. Mohorovicic table gives for P for Ottawa, distance 10,200 km. $= 13^m\, 12^s$. Hence P should arrive at Ottawa at $= 18^h\, 53^m\, 55^s$. Zeissig's table for 10,200 km., $S - P = 11^m\, 07^s$. Hence S should arrive at Ottawa at $= 19^h\, 05^m\, 02^s$. We see therefore what we read on the seismogram as P was undoubtedly S, although there is a difference of 18^s. Again when we take $O = 18^h\, 40^m\, 43^s$ and the distance, scaled on a 30-inch globe, from Ottawa to Spilko's epicenter, as 10,200 km., and divide the latter by 240, the rate of propagation of the L waves per minute, we obtain 42.5^m as the elapsed time. Hence the L waves should arrive at Ottawa at $19^h\, 23.2^m$, which is practically identical with the observed value. It may be remarked that the L waves travel with constant velocity only in an isotropic medium along the surface. However, this condition does not obtain, and hence we find for different earthquakes with rays traversing different regions, some variation in the velocity, lying between the limits of 200 to 240 km. per minute. On our velocity curves for *P*, *S*, and *L*, used for graphical application of recorded earthquakes, we have two straight lines for *L*, with respective velocities of 200 and 240 km.

The above record is then of the Pamirs earthquake. Knowing now the distance to the epicenter, 10,200 km., it is easy to reason *post facto* that it is somewhat improbable that we should easily be able to read an *i P*, since the angle of emergence for that distance is approximately 69°, and hence the horizontal component very small. However, again examining the seismogram for that day we find a very small, but sharp, *i* at $18^h\ 54^m\ 14^s$. This is 19^s later than our deduced *P*. Microseisms somewhat interfere in detecting an emersio for *P*.

We shall now evaluate the energy at the epicenter on the lines of Galitzin's investigation, utilizing our data from the seismogram of February 18, 1911. In the report of the Chief Astronomer for 1911 on page 23 will be found our value for absorption determined from the Turkestan earthquake on January 3-4 of the same year, and not so very far from the February earthquake, k being = .00032. The distance as above is 10,200 km., and for the density of the crust we retain the value of 2.8, which is approximately the mean of the various rock constituents (Smithsonian tables).

We have from the seismogram:

Amplitude	Period	Interval
x_N	T	t
μ	s	min.
20	30	7
40	20	11
30	16	3
20	12	16
10	16	25

From which we find

$$\Sigma \left(\frac{x_N}{T}\right)^2 t = .00006713 \text{ C.G.S.}$$

We were not provided with a vertical component seismograph in 1911, but the recent earthquake of September 7, 1915, has enabled us to obtain a ratio between the vertical and horizontal components for the long waves. This we find to be 1.40, instead of the theoretical 1.47, or Galitzin's observed value of 1.2. Hence the numerical coefficient 9.76 in equation (6) becomes 11.84.

Substituting the above values for Ottawa in equation (6) we find $E = 7.0 \times 10^{23}$ ergs C.G.S. Galitzin's similarly deduced value for the same quantity is 4.3×10^{23} C.G.S. Although the agreement is fairly satisfactory, yet it must be admitted that the reading of the seismogram upon which the result depends is not so simple a matter. In a good tectonic earthquake, distant say 6000 or 7000 km. or less, there would be no question in reading P and S; but when it comes to reading L, the various periods, their duration, their amplitudes, the different magnifications to apply,—we are plunged, if not into uncertainties, into complexities and perplexities, which are not likely to receive identical interpretation from experts. It is not desired to convey the idea that the results would be unreliable, but that the results would be discordant while probably of the same order of magnitude. In the above evaluation it may be pointed out that the absorption factor plays an important part, yet its value is known only within fairly large limits, as was pointed out in my report for 1911 referred to above,—and it is not necessarily a constant.

The value of Galitzin's investigation lies in the fact that he gives us some definite information, from Weber's figures, of the actual earth mass movement as 2.1 to 6.0×10^{23} ergs. It remains then for all seismologists who have a good record of the earthquake, and who know the constants of their instruments, to see whether the seismograms tell a similar story of the energy released in the Pamirs on February 18, 1911. It is hoped that the reproduction of Galitzin's article will stimulate the dynamic investigation of well recorded earthquakes.

In closing we may refer to the largest observed rock slide or rock fall in Canada, at Frank on April 29, 1903, when 70 lives were lost, and of which an official report was published. From it we find that the mass displaced was 40,702,000 cubic yards as determined from the old and new contours of the mountain. From the measurement of the debris the estimated mass was 36,000,000 cubic yards. In this latter report reference is made to two notable slides in Switzerland: the Elm slide of 12,000,000 cubic yards, when 84 houses and 115 lives were lost; and the Rossberg slide of 51,000,000 cubic yards, when four villages were destroyed and 457 lives lost. The Pamirs mountain fall (Bergsturz) was 3,270,000,000 cubic yards!