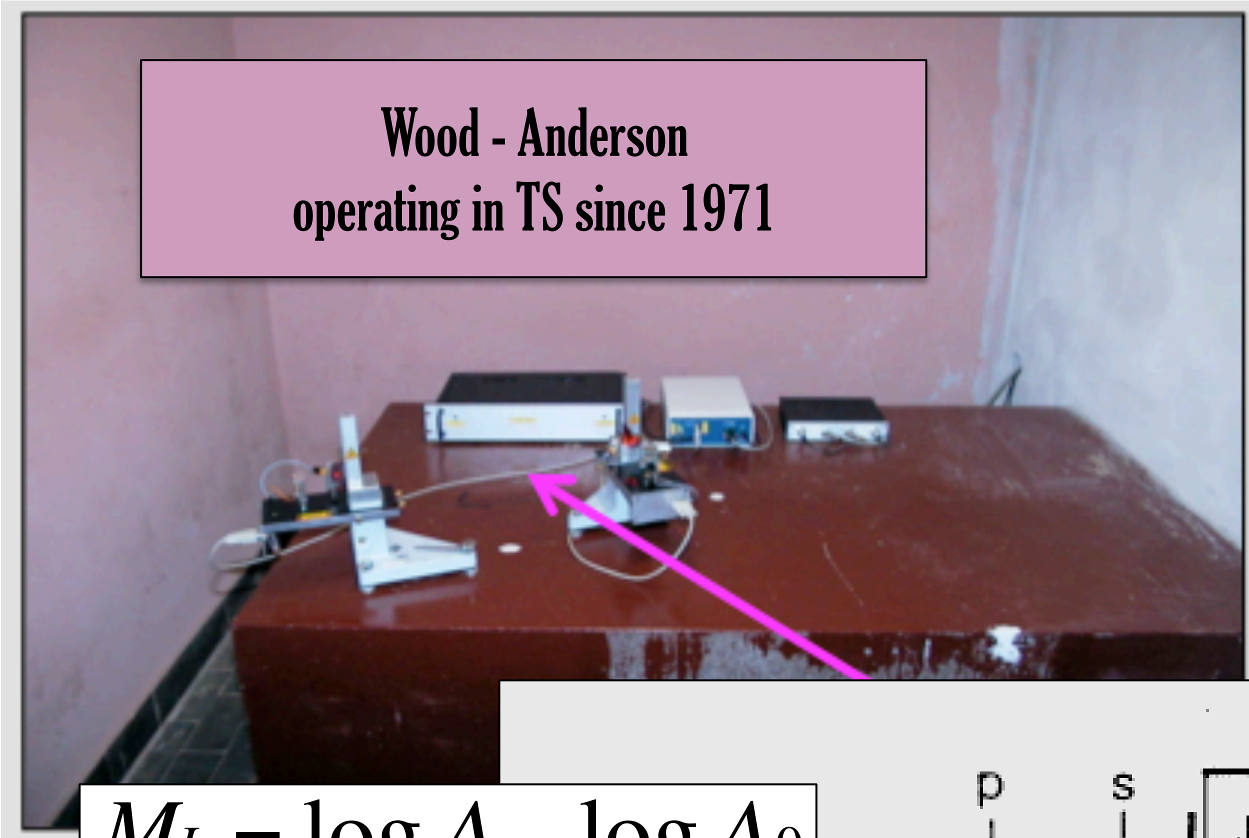
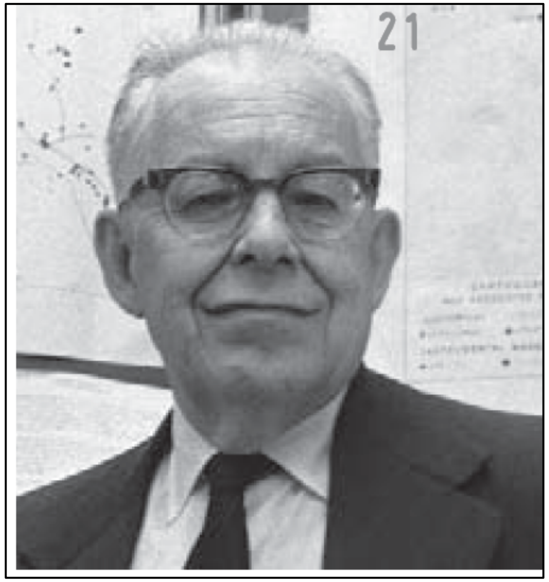
Modern earthquake magnitude estimations using old Wood-Anderson seismometers

by Denis Sandron

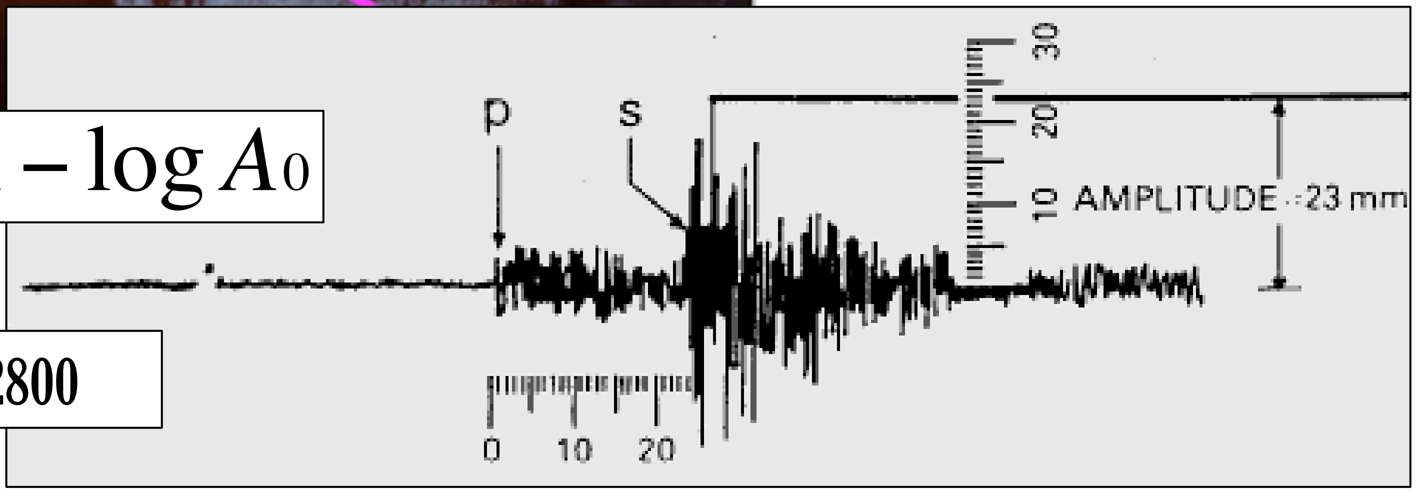
The concept of magnitude was introduced by Richter (1935) measured with the standard Wood-Anderson torsion seismometer (M_L)



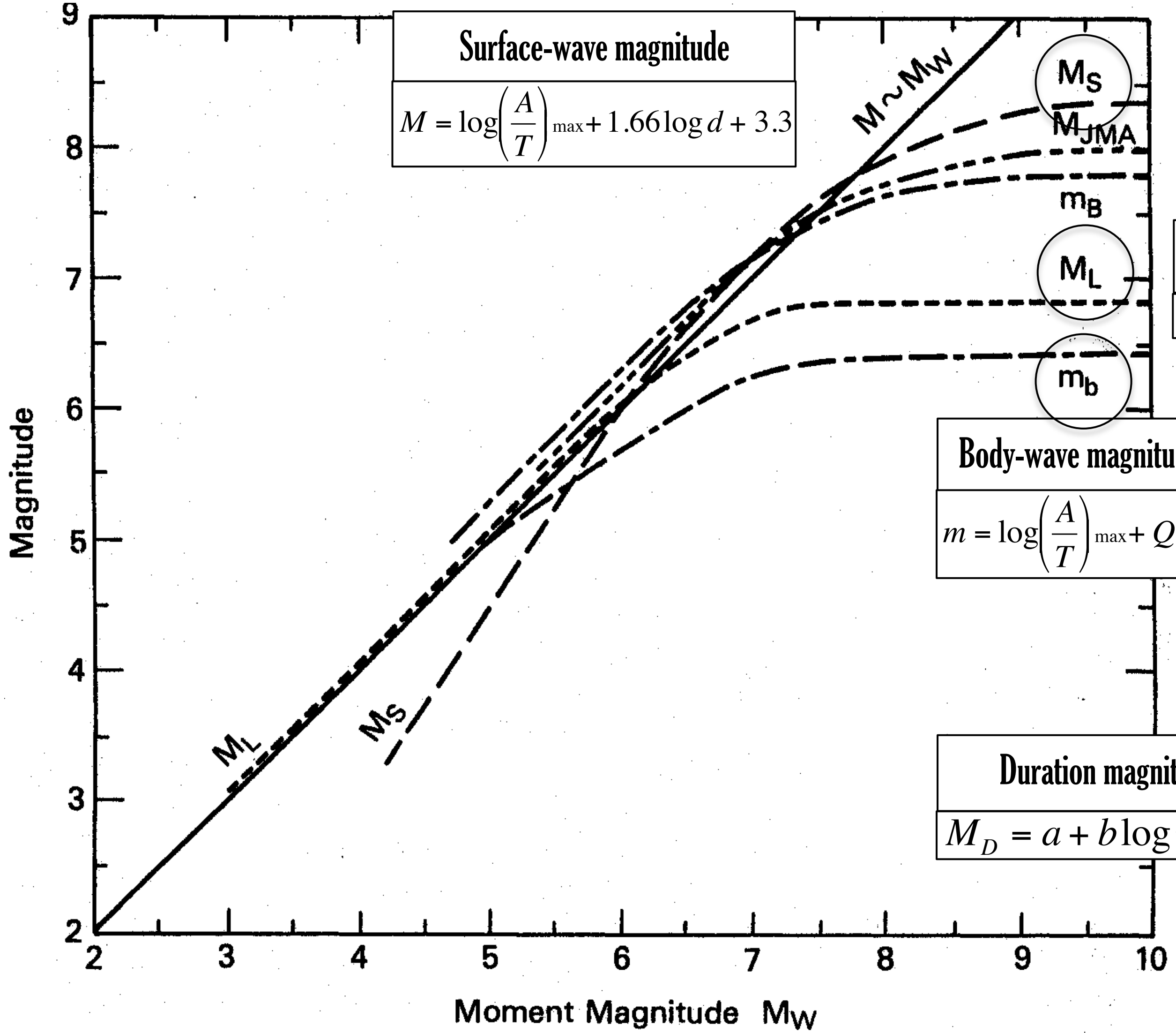


$$M_L = \log A - \log A_0$$

T_0=0.8, h =0.8, V =2800



comparison of the different magnitudes



Surface-wave magnitude

$$M = \log\left(\frac{A}{T}\right)_{\max} + 1.66\log d + 3.3$$

Body-wave magnitude

$$M_L = \log A - \log A_0$$

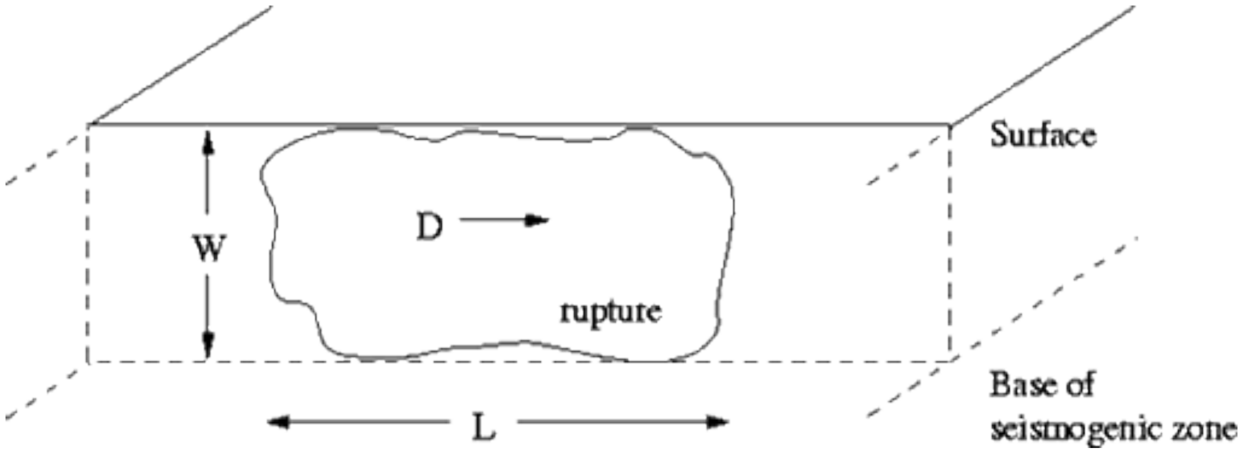
Body-wave magnitude

$$m = \log\left(\frac{A}{T}\right)_{\max} + Q + \varepsilon$$

Duration magnitude

$$M_D = a + b\log\tau + c\Delta$$

Kanamori (1977) has developed a standard magnitude scale that is completely independent of the type of instrument. It is called the Moment Magnitude, indicated with M o M_W, and it comes from the seismic moment M_0.



$$\boxed{M_0 = \mu A d}$$

where μ is the shear strength (rigidity modulus) of the faulted rock (about 3.3×10^{11} dynes/cm^2), A is the area of the fault, and d is the average displacement on the fault. There is a standard way to convert a seismic moment to a magnitude (Hanks and Kanamori, 1979):

with M_0 in dyne*cm.

$$\boxed{M_w = \frac{\log M_0}{1.5} - 10.7}$$

… Wood–Anderson again. Why?

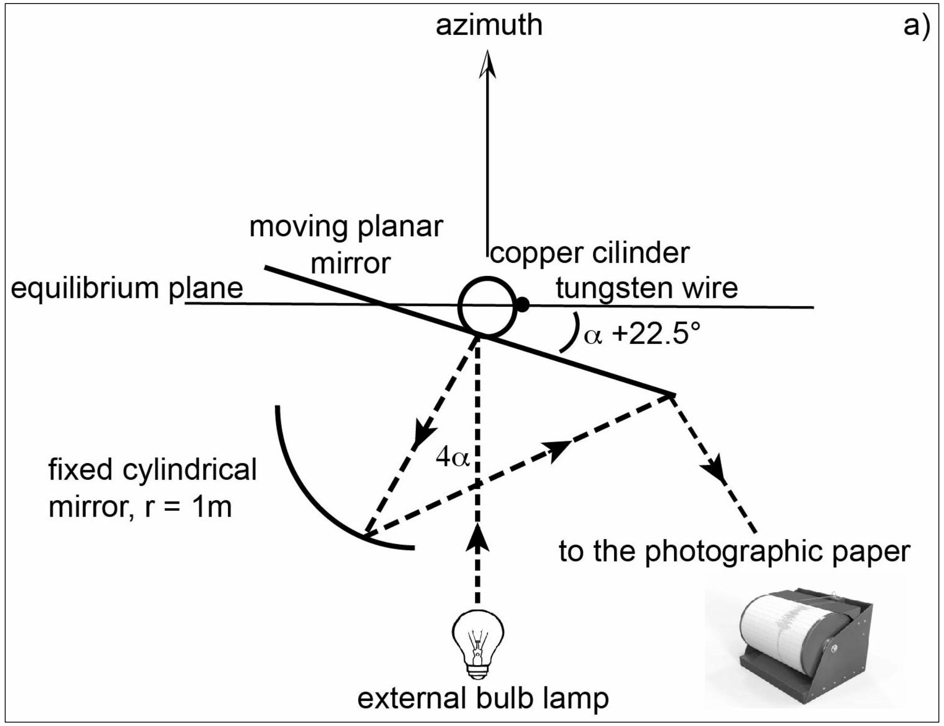
- Despite the paucity of WA instruments today, the M_L in its original form remains relevant for continuity with old earthquake catalogs and as a long-standing reference for all other magnitude scales up to approximately M_L 6.5. For larger earthquakes, the M_L scale progressively underestimates the actual energy release and M_L is said to saturate (Kanamori, 1983).
- Even so, M_L is a good predictor of structural damage caused by earthquakes because many buildings have resonant periods close to that of the WA seismograph (0.8 s).
- In Trieste there is one of the few stations equipped with an original pair of WA instruments that are still operating.

The Wood–Anderson of Trieste

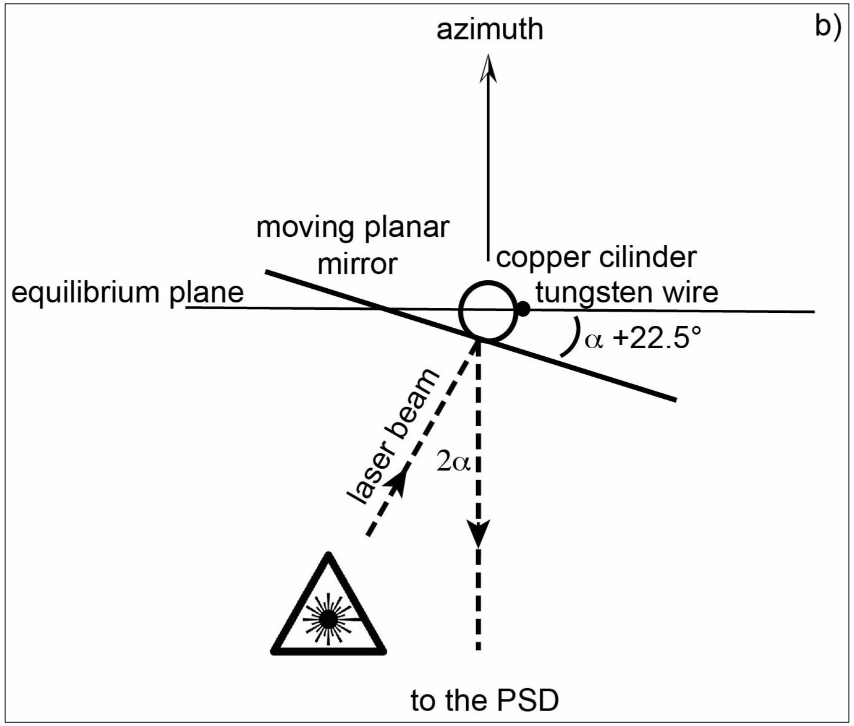
- Two horizontal WA seismometers, installed in 1971, are still operating at the Trieste station (in northeast Italy) after having been restored and modernized in 2002 through the replacement of the recording on photographic paper by an electronic device.
- The original M_L values related to the Trieste WA were published in bulletins up to 1989.
- We generated a new catalog from digital data after 2002 by taking the locations in different national and international catalogs.
- After the analysis described in this paper, we carefully revised the magnitudes of the old data to remove the bias of ~0:2 units introduced by past errors in the old bulletins.
- We compiled a new catalog of 1522 WA M_L values for the time window 1977–2013 for events with magnitude $0:2 < M_L < 6:6$.
- The new catalog can be downloaded from the Centro Richerche Sismologiche (CRS)– OGS website.

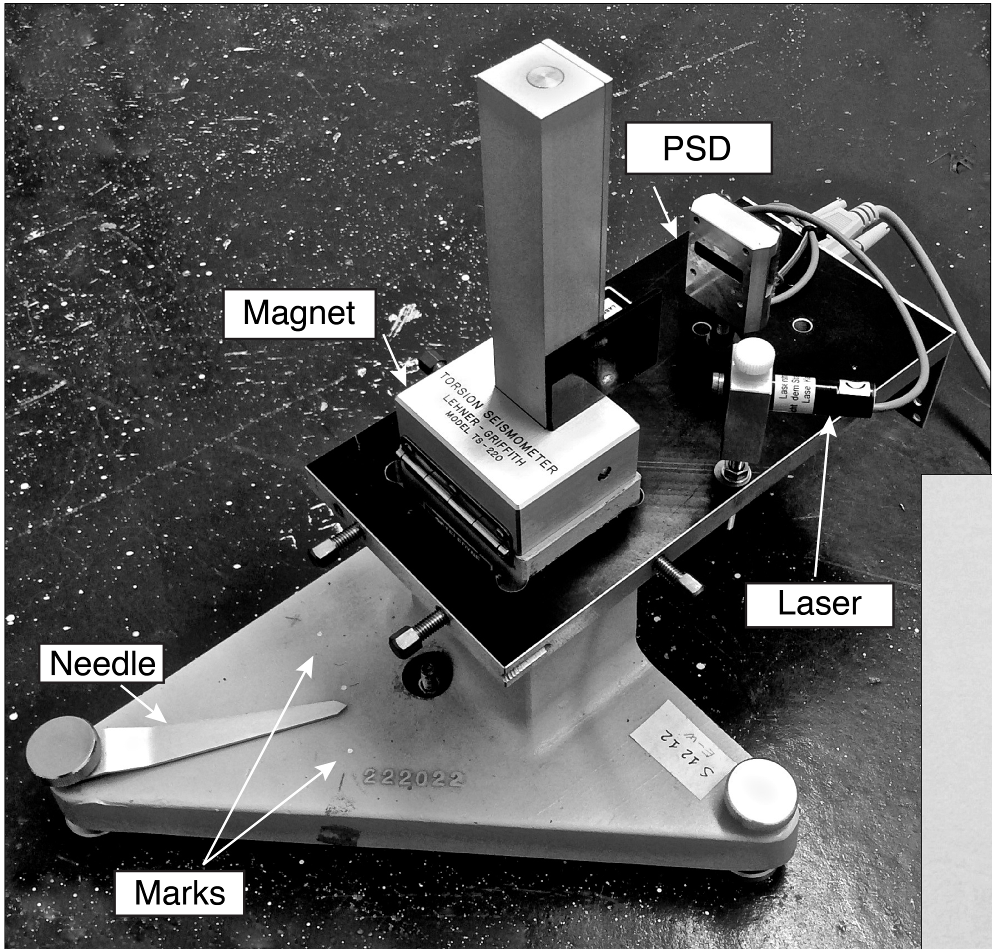
The Wood–Anderson of Trieste

Before 2002

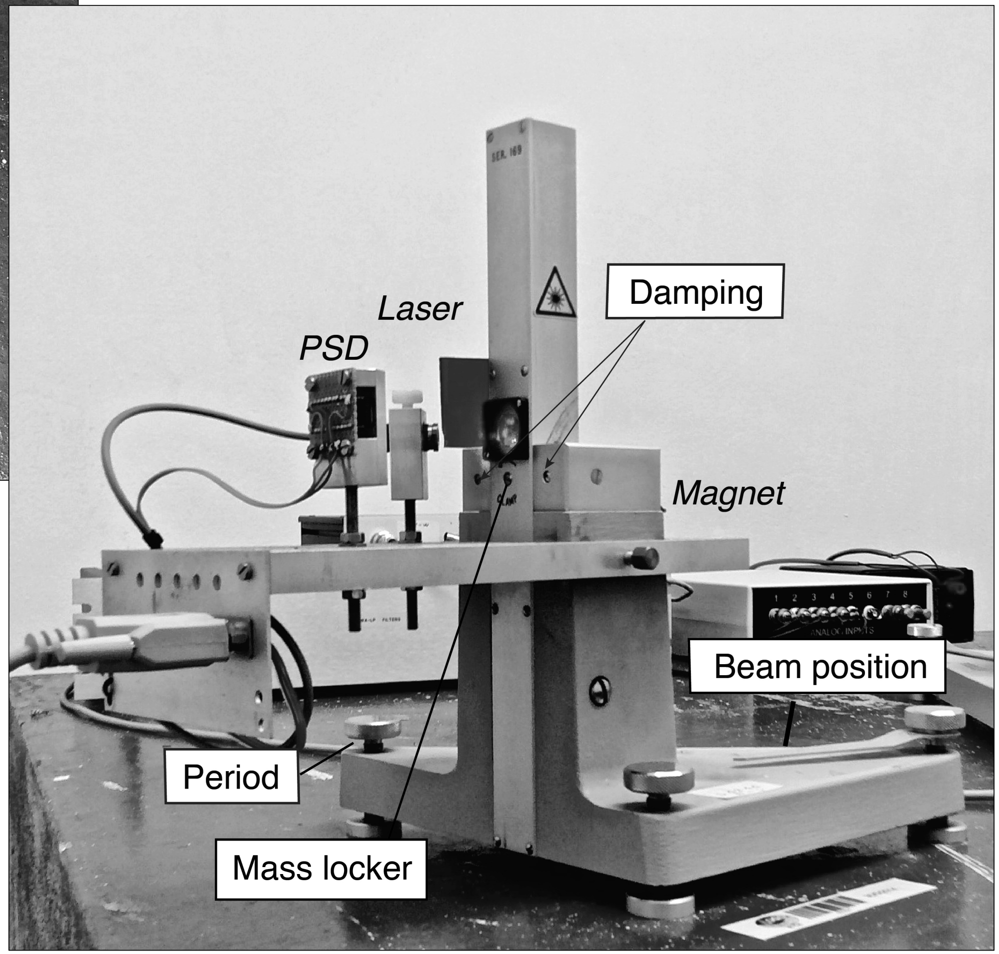


After 2002

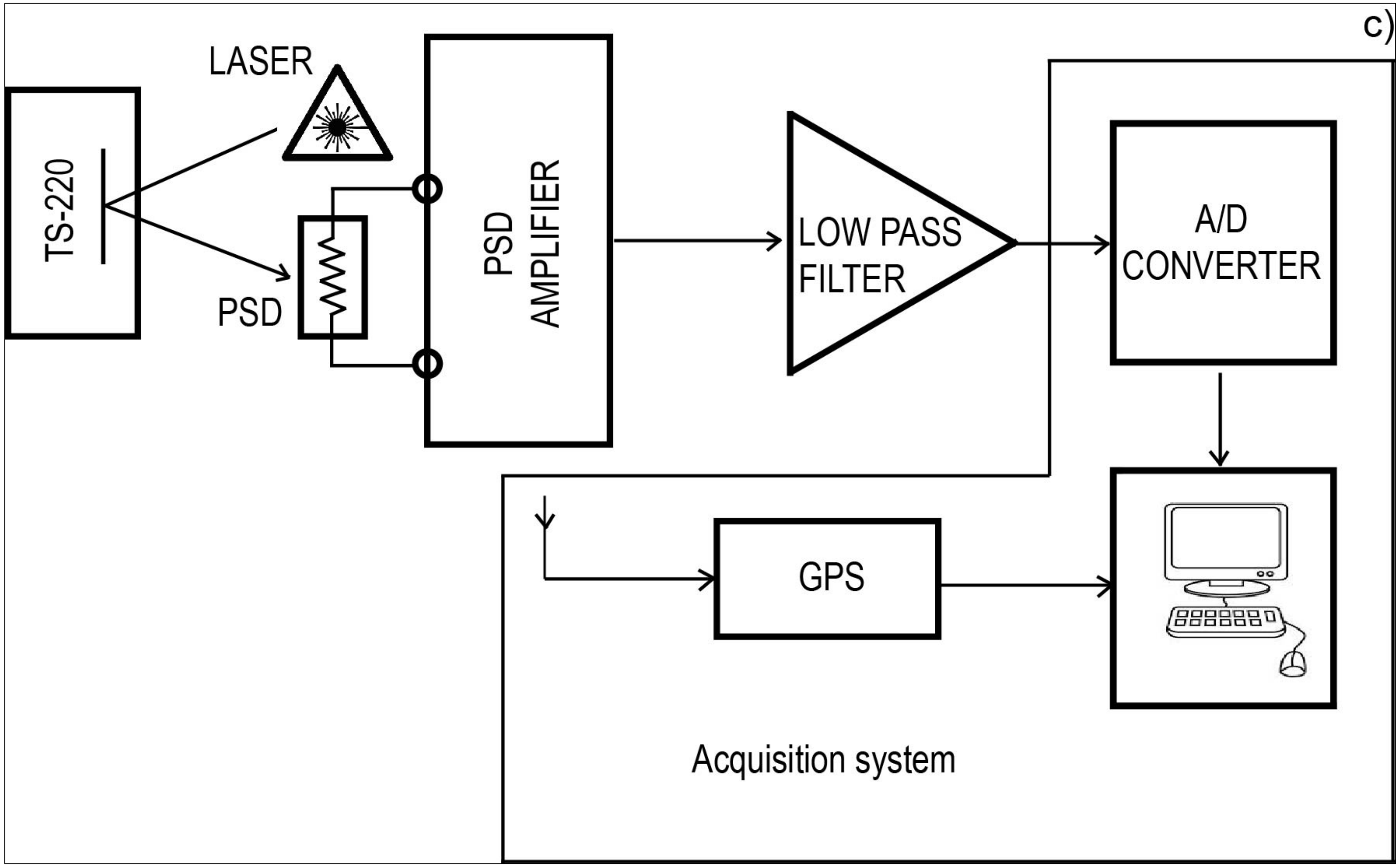




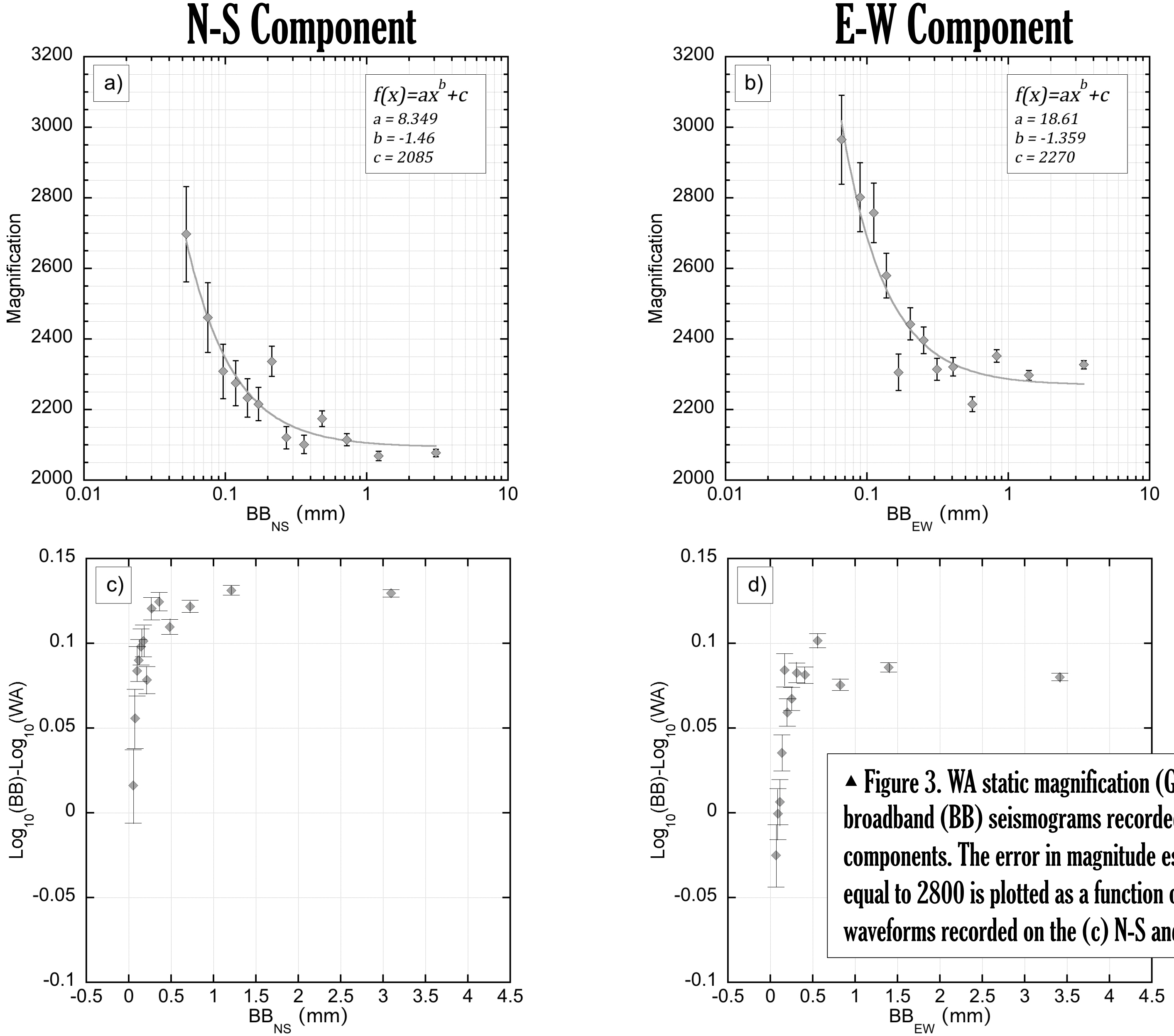
▲ Figure 2. (a) Top view and (b) side view of the Wood–Anderson seismometer currently operating in Trieste. The screws for tuning the beam position, the period and the damping factor, and for blocking the mass of the instrument are shown in the side view.



The WA of Trieste: recording and acquisition system

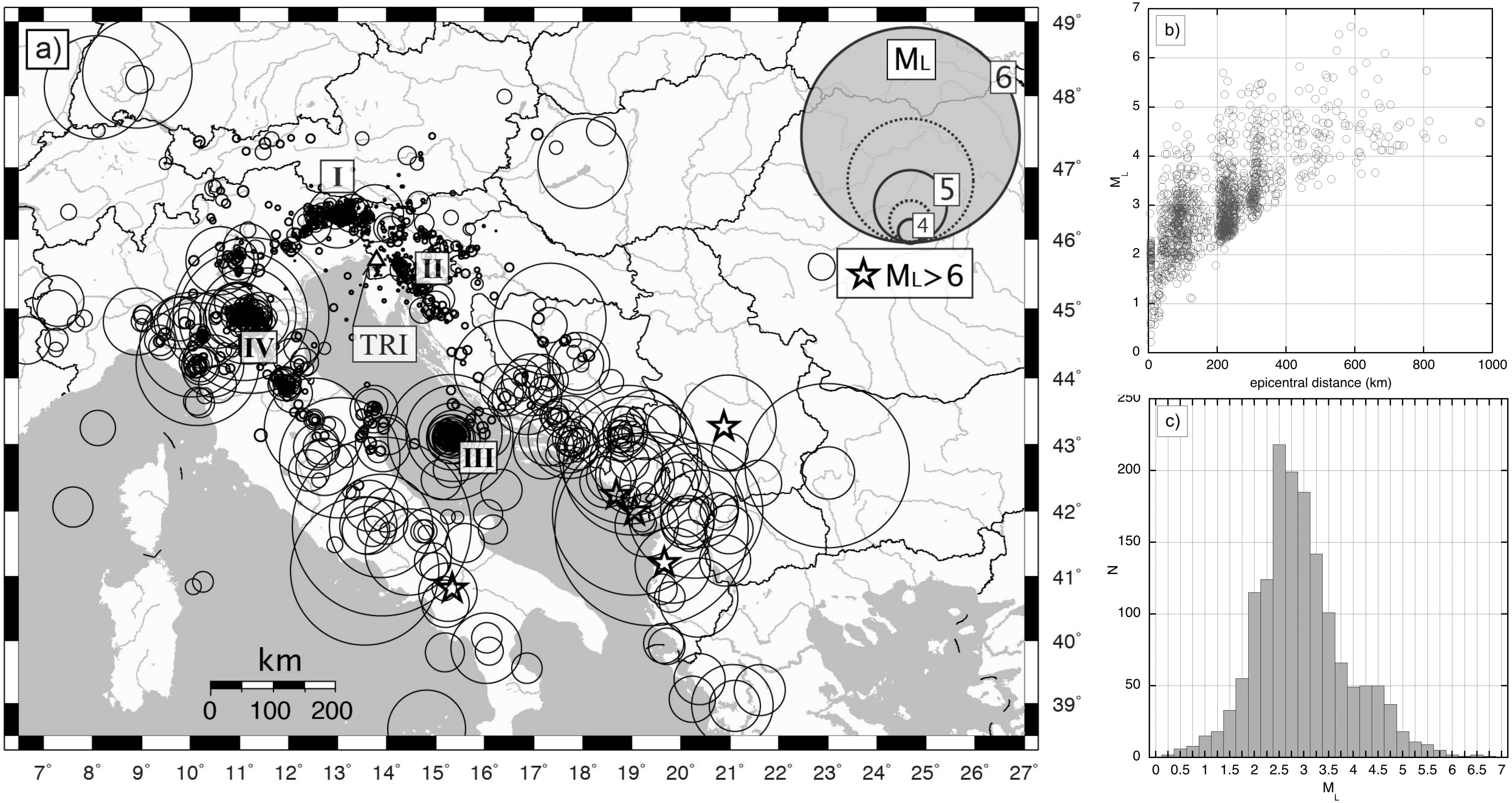


Validation of the upgraded instrument



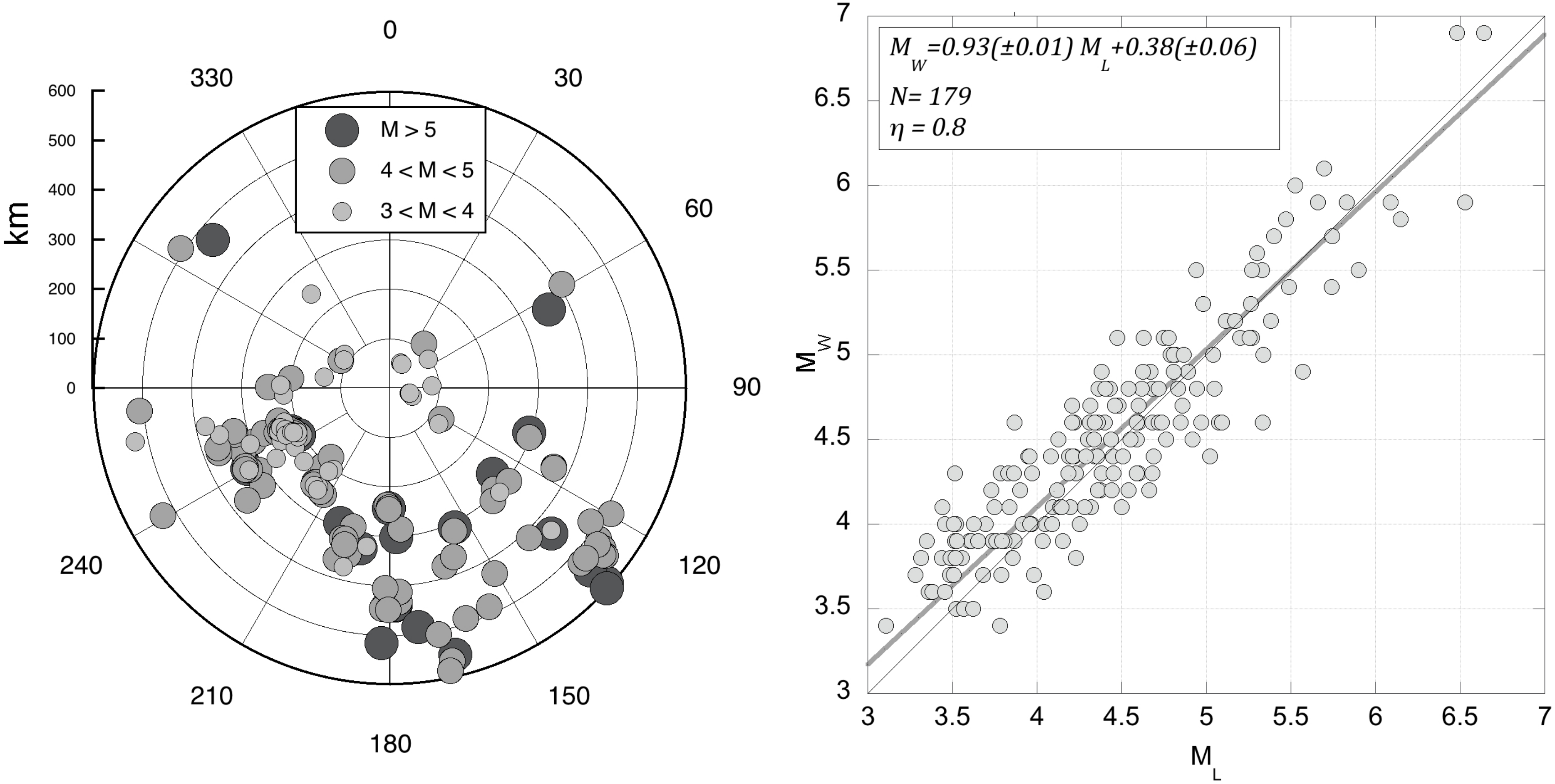
▲ Figure 3. WA static magnification (Gs) versus amplitude of the broadband (BB) seismograms recorded on the (a) NS and (b) EW components. The error in magnitude estimation due to setting Gs equal to 2800 is plotted as a function of the amplitude of the waveforms recorded on the (c) N-S and (d) E-W components.

The new catalog of M_L



▲ Figure 4. (a) Epicenters of the earthquakes (circles proportional 13 to M_L) recorded by the Trieste WA (TRI; white triangle) and investigated in this study. The zones of clustered events are I, the Friuli region; II, Dinaric region; III, Adriatic Sea; and IV, Emilia region. M_L is shown as (b) a function of epicentral distance and (c) a histogram of M_L with bins sized at 0.25 magnitude units.

Wood – Anderson vs Moment Magnitude M_W



▲ Figure 7. M_L–M_W data set: (a) Azimuth versus distance of con- sidered earthquakes with respect to the Trieste WA seismometer. Circle sizes are proportional to the earthquake magnitudes, and the maximum distance is 600 km. (b) Orthogonal regression fit (thick gray line). N is the number of data.

Conclusions

Other issues that were addressed in our study show that the following:

- The proper static magnification Gs of the WA depends on the recorded wave amplitudes and approximately follows a power law, ranging from 2800 for amplitudes of 0.05 mm and reaching an asymptotic value of 2080 for amplitudes >1 mm. In this paper, we assumed a variable Gs to obtain the proper equivalent M_L using the data from the broad- band instruments.
- The M_L computed by the simulated WA seismograms recorded at the top of Grotta Gigante have a constant bias with respect to the broadband instruments located at the bottom of the cave.
- The relationship found between the M_L and the M_W shows a general underestimation of ~0:2 magnitude units for M_L.

Denis Sandron, Giovanni Francesco Gentile, Stefania Gentili, Angela Saraò, Alessandro Rebez, Marco Santulin, and Dario Slejko. *The Wood–Anderson of Trieste (Northeast Italy): One of the Last Operating Torsion Seismometers.* Seismological Research Letters Volume 86, Number 6 November/December 2015 doi: 10.1785/0220150047