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MAGNITUDES FROM SIGNAL DURATION COMPILED AT THE PACIFIC GEOSCIENCE CENTRE

by

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Internal report of the Earth Physics Branch, Pacific Geoscience Centre

No. 81-2

Abstract

Magnitudes based on the duration of signal of local earthquakes have been computed on a routine basis for three years as part of the WCTN Preliminary Epicentre Program. Comparison with magnitudes published for the same earthquakes in Earth Physics Branch catalogues shows that the duration magnitudes are more internally consistent, having an average standard deviation of 0.15 versus 0.25 for the published values. Comparisons with magnitudes calculated with readings from the VIC Wood Anderson seismographs show that the duration magnitudes more accurately represent values consistent with the original M_L definition and that magnitudes currently published as M_L by the Earth Physics Branch are systematically 0.4 magnitude units too low in the WCTN area.

Introduction

Most of the earthquakes recorded by the Western Canadian Telemetered Network (WCTN) are within 200 km of the array. Magnitude values for the annual catalogue are calculated from maximum amplitudes on short period vertical (SPZ) instruments and epicentral distance using Richter's formula for local earthquakes in California (Gutenberg and Richter, 1956). These magnitudes suffer from all the problems of computing magnitudes of earthquakes in the near field with short period vertical seismographs (e.g. see Eaton et al. 1970). The most significant of these problems are.

1) Focal depth cannot be ignored at small epicentral distances, particularly in this region where a significant proportion of events are deeper than 50 km.

2) The high frequency response of modern SPZ instruments peaks in the flat portion of the Wood Anderson seismograph response making the determination of the period of the maximum amplitude critical and a significant source of error.

3) Richter magnitudes are based on averaged horizontal motion whereas all WCTN are SPZ stations.

4) Reflected and converted phases in the crust confuse the maximum amplitude decay function in the near field deviating significantly from simple geometric spreading.

5) The radiation pattern due to source function varies significantly in the near field.

Magnitude computed by signal duration, Figure 1, was first proposed for local earthquakes by Tsumura (1967). He noted that the signal duration of earthquakes within a few hundred kilometers correlated well with Richter magnitudes and had the added advantage of being very insensitive to epicentral (and thus hypocentral) distance. Because of the problem of determining maximum amplitudes on develocorder records, this method was used by Lee et al. (1972) in California and Crosson (1972) in Puget Sound to compute magnitudes. Like Tsumara, they developed relationships between log duration and Richter magnitudes based on horizontal Wood Anderson records or equivalent (see Tsumara, 1967; Lee et al., 1972 and Crosson, 1972, for details).

M_L VS M_D Analysis

The validity of using duration as a magnitude indicator is well established by the Japanese, California and Washington studies. Because the method showed promise that it may be superior to using SPZ amplitudes in the near field, (e.g. see Real and Teng, 1973) a research project was set up to evaluate the effectiveness of computing duration magnitudes on a routine basis during the processing of WCTN data. Some preliminary experimentation in 1976 indicated that Crosson's (1972) relationship was the most appropriate and after an initial training and interaction period to define effective criteria and procedures, duration magnitudes were routinely computed from WCTN helicorder records for earthquakes within the WCTN area starting in January of 1977. The signal durations were measured mainly by one person (Mike Gregory). The data gathering for this project came to an unexpected halt when the WCTN operating system switched over to RSX11 early in 1980. At this time the helicorder playouts could no longer be filtered at the same high frequency cut. Duration magnitudes continued to be computed but initial evaluation suggests that duration magnitudes may be frequency dependent and that the additional high frequency in the helicorder records may require a change in formula and possibly result in a larger standard error. These preliminary observations must await the gathering of a further body of data but are supported by the conclusions of Bakum and Lindh (1977).

The analysis here is thus based on 3 years of data, 1977 to 1979 from 4 WCTN stations. In February 1978 VIC closed and PGC opened, both stations had the same gain and band width. There are 96 events with both EPB M_L values and M_D values in the WCTN region. Magnitudes (M_L) range from .6 to 4.1. Unfortunately there are only Wood Anderson records for 9 of these events because the Wood Anderson seismographs did not record the smallest events and because it was decided not to continue running Wood Anderson seismographs when the seismograph station was moved from the Astrophysical Observatory to the Patricia Bay site in February 1978.

Internal Consistency

In order to judge the internal consistency of each set of magnitude values the standard deviations for each set were simply added up and averaged. The mean standard deviation for the EPB M_L set is 0.25 and that for the M_D set is 0.15 suggesting the M_D values are a more consistent measure. The same conclusion was reached by Real and Teng (1973).

Evaluation of Crosson's Formula

The formula that has been used to compute the M_D values is that of Crosson (1972). Comparing the two sets of magnitude values shows that the M_D values computed with Crosson's formula are systematically higher than the EPB

M_L values by about ¼ to ½ a magnitude unit over the range of data we are comparing (Figure 2).

Effect of Focal Depth

The data have been divided into two depth ranges, shallower and deeper than 30 km. The relation between M_D and EPB M_L values is noticeably different for the deep and shallow events (Figure 2). This is perhaps to be expected, not because of a change in M_D values, but because the EPB M_L values for deep events deviate most from the original definition of Richter M_L. The M_D values, being essentially independent of distance, should be more consistent for deep events.

Developing a new M_D Formula

We first assumed that the EPB M_L values, even though they suffer from a larger standard deviation are, on average, the best estimate of the magnitudes available (see later section on Wood Anderson comparison showing this was an questionable assumption). EPB M_L values from the catalogue are thus regressed against $\log_{10}$ of the signal duration for each station and for both depth ranges. A linear regression was chosen as other studies (Real and Teng, 1973; Bakum and Lindh, 1977) have shown this is appropriate over a small range of magnitudes even though theoretical studies (Suteau and Whitcomb, 1979) suggest a quadratic relationship is more appropriate. Figure 3 shows the relationship for each station for all data. The relationship is similar for all stations with PGC having the most anomalous slope. Because PGC (and VIC before it) is the closest station to most of the deeper events, it was thought that inappropriate EPB M_L values might be influenci the relationship. Just shallow events are plotted in Figure 4 and the deviation of PGC is somewhat less. Relationships for all stations are again very close with ALB standing out as consistently having a slightly shorter duration. This may be caused by weak dependence on distance that others have found (e.g. Tsumura, 1967, Lee et al. 1972), as ALB is most often the farthest station. It should be noted that although HYC was running at twice the gain of the other stations for all of this period, it does not have significantly longer coda lengths.

Since no station is significantly different from the rest it was decided to use the average duration to define a M_D formula. A slightly more consistent data set could be obtained if individual station formulas are used as Ellis and Chandra (1981) have done. Figure 5 compares the relationships of average duration for all data, for deep and for shallow events. Again, because the deep events may be influenced by inappropriate EPB M_L values, the shallow data set is chosen as being the most appropriate for defining a new M_D formula.

Comparison with other relationships

Figure 6 is a plot of selected M_L versus M_D relationships in the literature. The most anomalous one in both intercept and slope is that of Lee et al. (1972) for California. This appears to be due both a regional variation and instrument difference (see discussion in Bakum and Lindh (1977)). The relationship is similar to relationships found for northern California by Bakum and Lindh (1977) but different from the relationships for southern California defined by Real and Teng (1973) which are similar to the majority of relationships in Figure 6. The other anomalous relationship is that of Hyndman and Rogers (1981) for OBS events. These events have a much longer duration than land events that is caused by reverberation in the oceanic sediments and were recorded in a higher frequency band than typical SPZ land stations. The similar slopes of the rest of the relationships suggest a similar physical law governs the wave scattering process that forms the coda but that station magnifications, the Q of the local crust and the accuracy of the local M_L scale may influence the intercepts (see Suteau and Whitcomb, 1979).

Comparison with Magnitudes Calculated from Standard Wood Anderson Seismographs

There were clear Wood Anderson records on microfilm for 9 of the earthquakes recorded in 1977 and early 1978. Magnitudes were computed for these events in the original manner of Richter using the nomogram published by Gutenberg and Richter (1942). Values were also computed using hypocentral distance rather than epicentral distance as there is a significant difference for some of the deeper events and this is more in keeping with the attempt to deal with geometric spreading of seismic waves that is embodied in the original definition of local magnitude. The various magnitude values for the 9 events are tabulated in Table 1. There is not a sufficient number of events to derive a reliable relationship but it is apparent in Figure 7 that there is not a 1 to 1 correspondence between the EPB M_L values and the Wood Anderson M_L values. Simple averaging (Table 1) suggests a 0.41 difference. Part of this difference is accounted for in the hypocentral/epicentral distance substitution but a difference of 0.29 magnitude units is found when using epicentral distance. This would correspond to a difference between the vertical and horizontal amplitudes of 1.9 (i.e. $\mathrm{alog}_{10}.29$) which is larger than is observed. Thus, there must also be some systematic problem accommodating the different frequency responses of a modern SPZ instrument and a Wood Anderson seismograph.

There is a good correspondence between the Wood Anderson M_L values and the M_D values computed with Crosson's (1972) relationship (Figure 8). These M_D values are clearly better related to the Wood Anderson M_L values than the EPB M_L values. This is perhaps not surprising as Crosson's (1972) relationship was based on comparing average duration with Wood Anderson M_L values.

If the 0.41 difference suggested by Table 1 and Figures 7 and 8 is added to the formula derived here for the shallow events (Figure 5), then the result is very close to Crosson's (1972) relationship. Since Crosson's formula is calibrated directly with Wood Anderson M_L values and over a a larger magnitude range than this data set, it seems logical to continue using that relationship for computing magnitudes in the WCTN area.

Conclusions

The magnitudes presently calculated and reported as M_L for the WCTN region in Earth Physics Branch catalogues are on average 0.4 lower than M_L values computed with standard Wood Anderson Seismographs and show a standard deviation of 0.25. By switching to magnitudes calculated from signal duration, using the formula developed here or Crosson's (1972) formula, the offset in magnitudes would be corrected and the standard deviation reduced to about 0.15. The standard deviation could probably be further reduced by using magnitude formulas derived for individual stations. Three years of routine calculation of duration magnitudes show they could be easily integrated into routine processing for catalogue purposes.

Recommendations

1. Duration magnitudes should continue to be calculated on a routine basis for earthquakes in the WCTN area.
2. Duration magnitudes should become the published magnitude for earthquakes in the WCTN area either by filtering the WCTN output to be equivalent to pre-RSX-11 data and using Crosson's (1972) M_D relationship, or by developing a new M_D relationship based on the present WCTN bandpass. (The former is preferred for consistency with the response of other Canadian short period stations.)
3. The above observations emphasize the value of Wood Anderson seismographs for providing a reference standard and I suggest the existing instruments be reactivated at the Pacific Geoscience Centre. (Note that both the University of Washington in Seattle, Washington and the USGS at Newport, Washington run pairs of Wood Anderson seismographs by using helicorder playouts with a Wood Anderson response).

4. The saving and playback criteria of WCTN digital data should be adjusted so that signal duration can be routinely measured for events not on helicorders.
5. A study be undertaken to compare VIC Wood Anderson magnitudes with published EPB M_L values over a longer period of time and a larger geographical area. (Wood Andersons were operating at VIC from 1967 to February 1978).
6. Consideration be given to establishing Wood Anderson seismographs at other photographic observatories (i.e. PNT and PHC) for a period of several years to calibrate the M_L magnitude scale used in western Canada.

Table 1

Comparison with standard Wood Anderson seismographs from magnitudes

Event Day				M_L(EPB)	M_L(R)	M_L(R+HYPO)	M_D	Depth (km)	Epicentral Distance VIC (km)
77	02	03		2.4	2.8	2.9	2.8	12	28
77	05	26		3.5	3.9	3.9	3.4	10	311
77	06	17		3.4	3.1	3.1	3.8	11	103
77	06	23		3.5	3.5	3.5	3.8	21	59
77	07	25		3.4	3.5	3.7	3.7	56	65
77	08	28		2.3	2.7	3.0	2.9	51	39
77	10	14		2.9	3.5	3.5	3.8	25	106
77	10	15		2.5	3.0	3.4	3.1	42	37
78	03	05		3.4	3.9	4.0	3.8	54	62
			Total	27.3	29.9	31.0	31.1		
			Mean	3.03	3.32	3.44	3.45		

Differences of Mean Values

$M_L(\mathrm{R+HYPO}) - M_D = 0.01$

$M_L(\mathrm{R+HYPO}) - M_L(\mathrm{EPB}) = 0.41$

$M_L(\mathrm{R}) - M_L(\mathrm{EPB}) = 0.29$

Definitions:

M_L(EPB): M_L as it appears in the EPB catalogue. This is calculated from maximum amplitude on vertical SP instrument.

M_L(R): M_L as defined by Richter. Average of two horizontal components of Wood Anderson seismographs at VIC using epicentral distance and nomogram.

M_L(R+HYPO): As in M_L(R) except hypocentral distance is used.

M_D: M_D calculated by routine processing of WCTN epicentres using Crosson's (1972) formula: $M_L = 2.82 \log_{10} \tau - 2.46$

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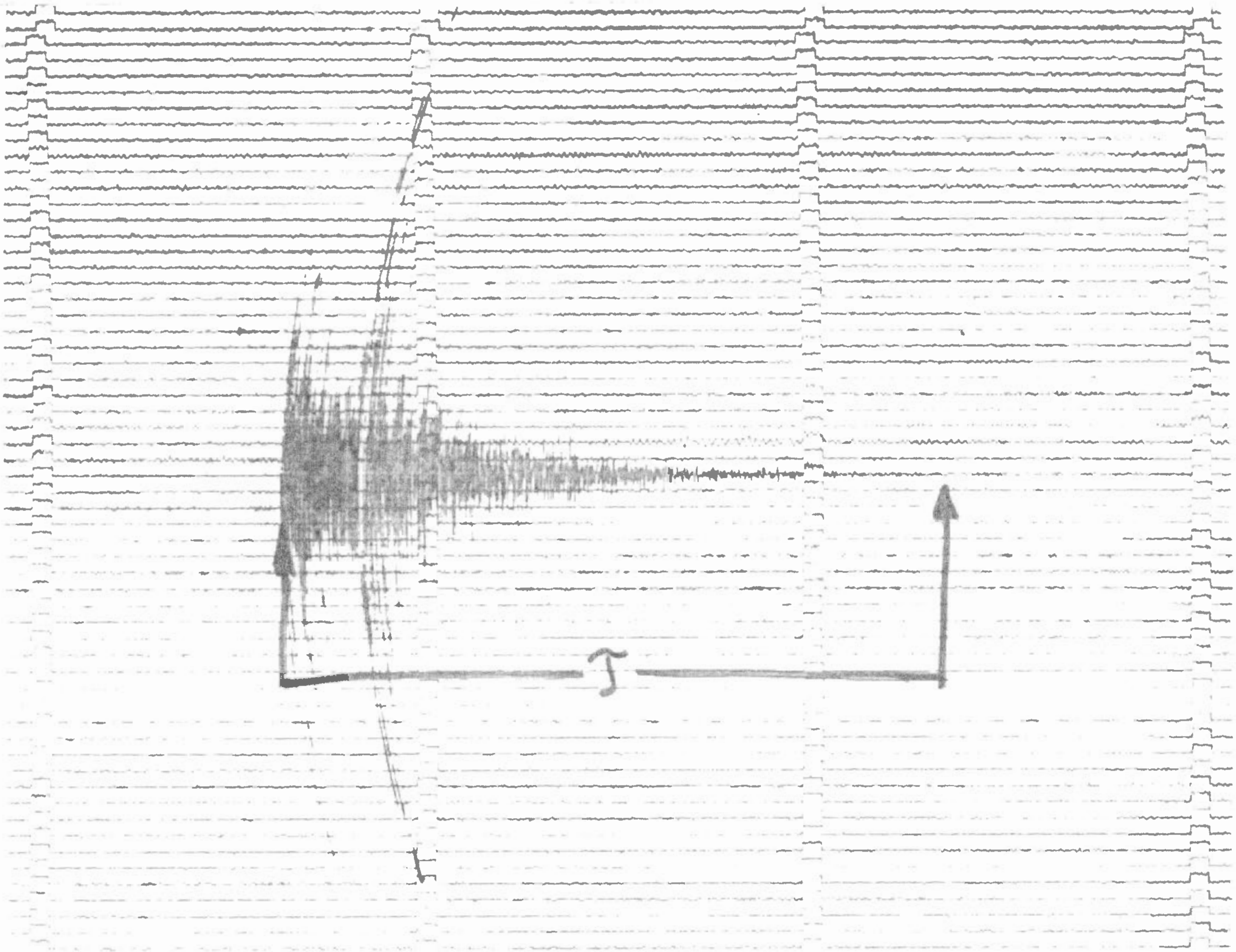


Fig. 1: Coda length duration: defined as the time from the initial P onset until the signal returns to the former background level.

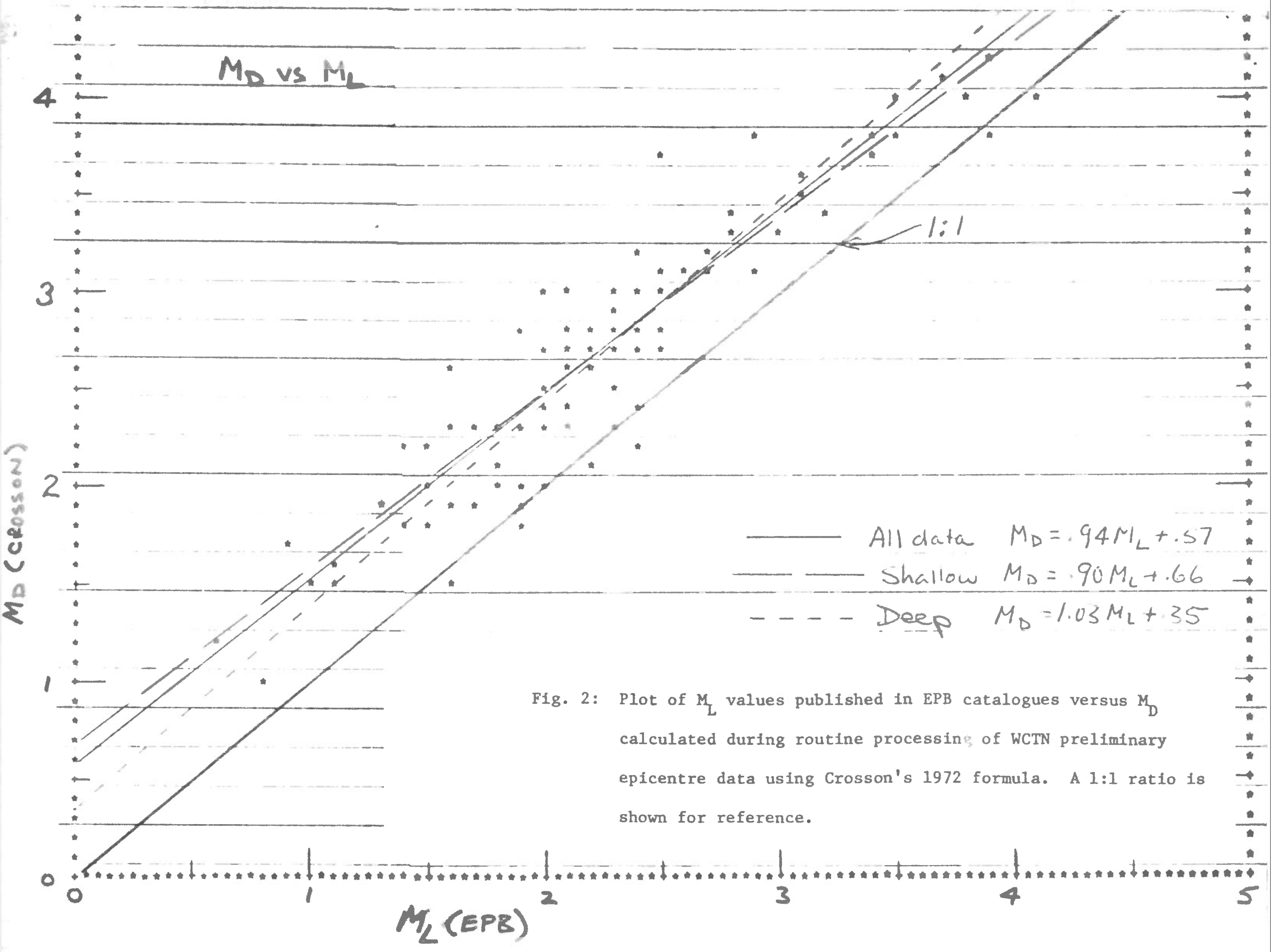


Fig. 2: Plot of M_L values published in EPB catalogues versus M_D calculated during routine processing of WCTN preliminary epicentre data using Crosson's 1972 formula. A 1:1 ratio is shown for reference.

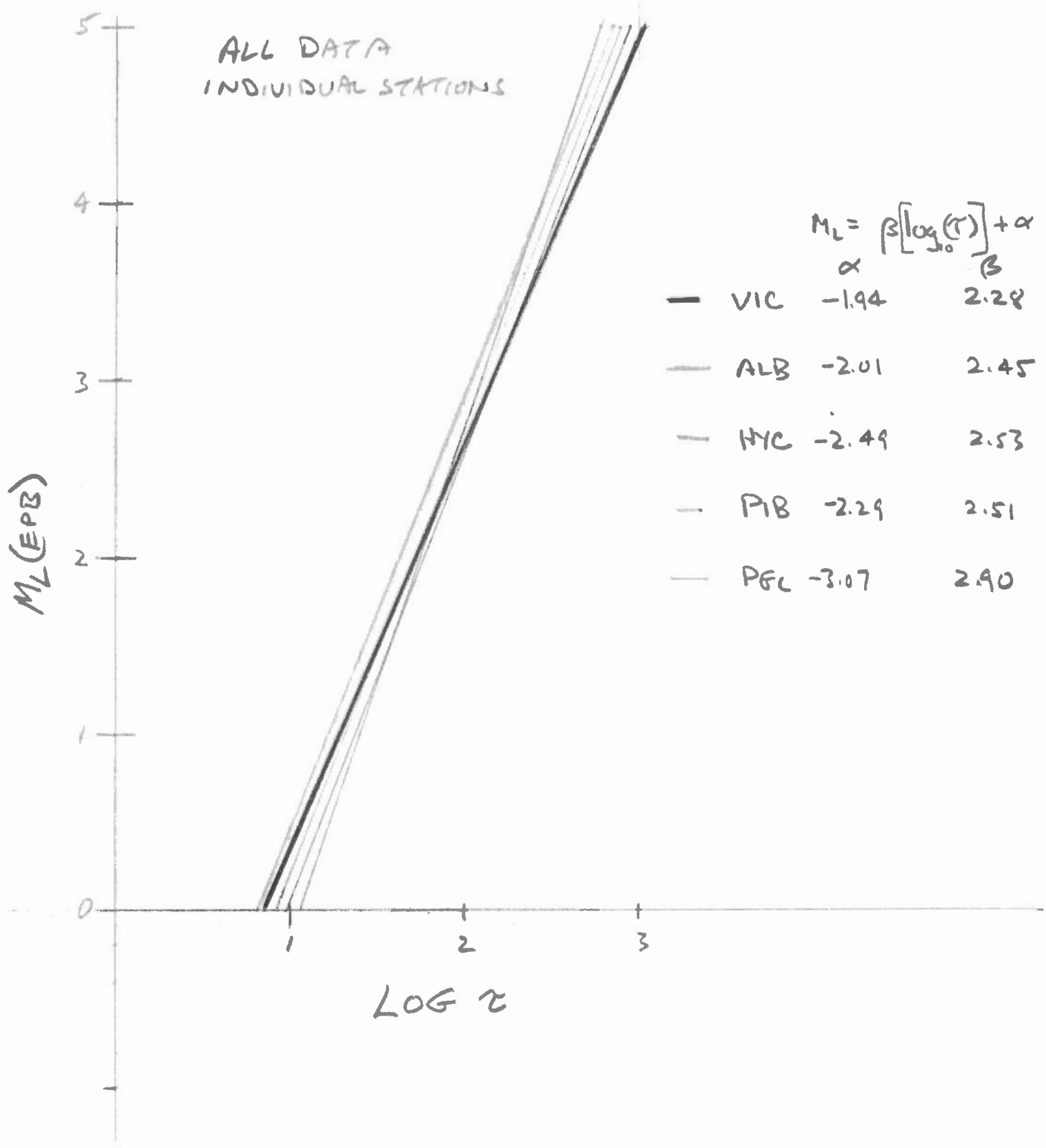


Fig. 3: Plot of M_L from EPB catalogues vs the log of the duration at individual stations.

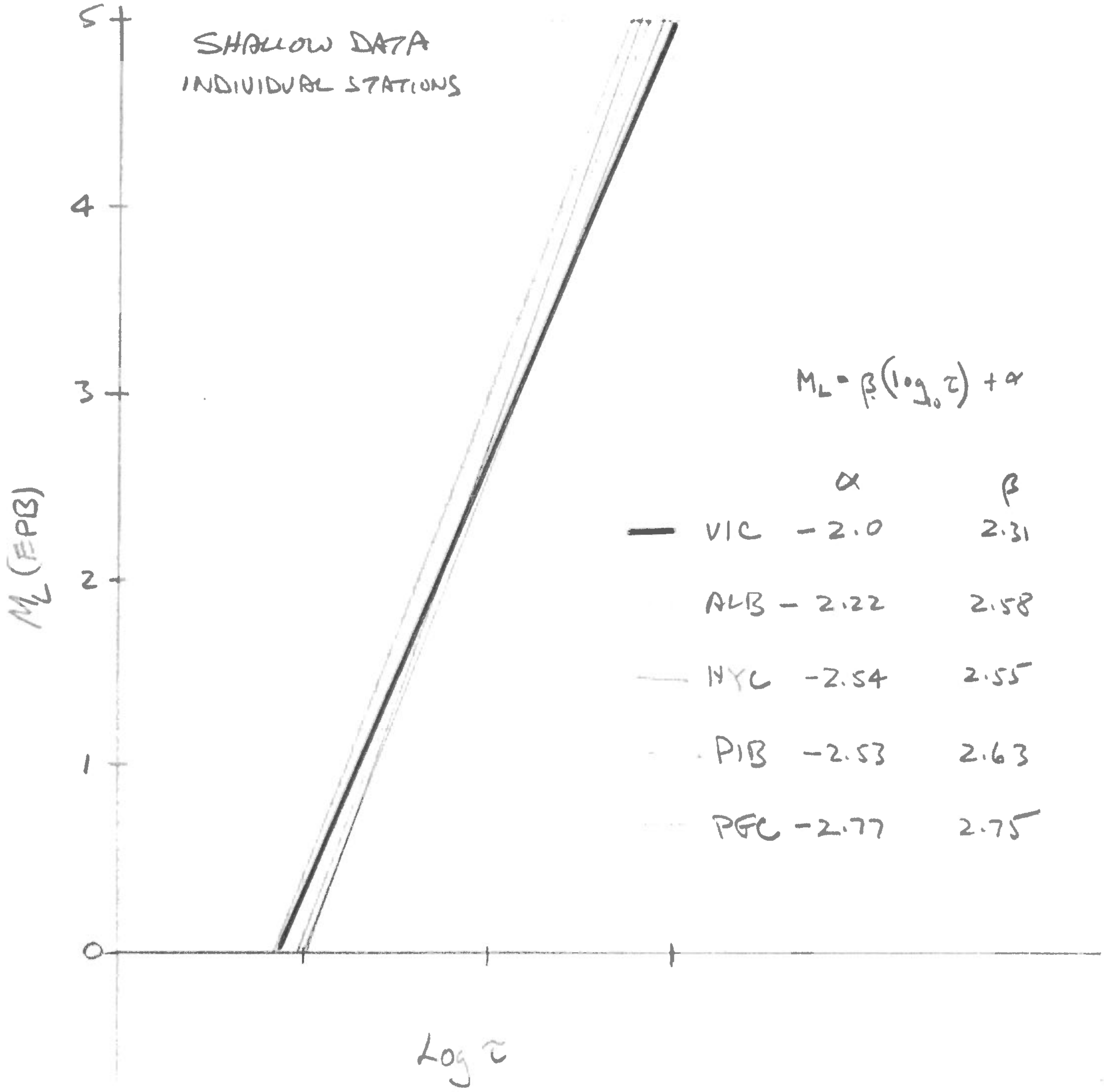


Fig. 4: Plot of M_L published in EPB catalogues vs the log of the duration at individual stations. Only earthquakes with focal depth less than 30 km are used.

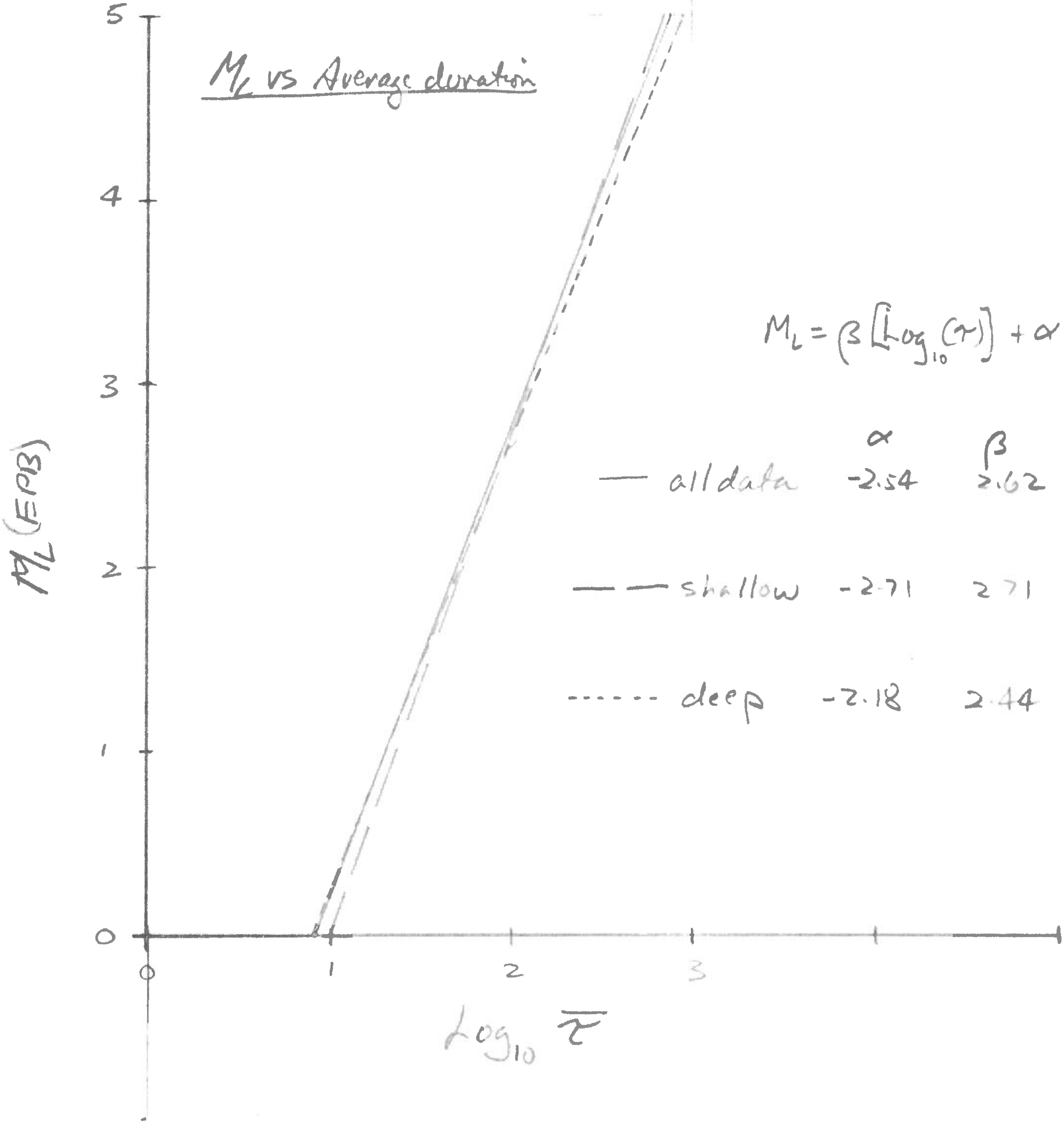
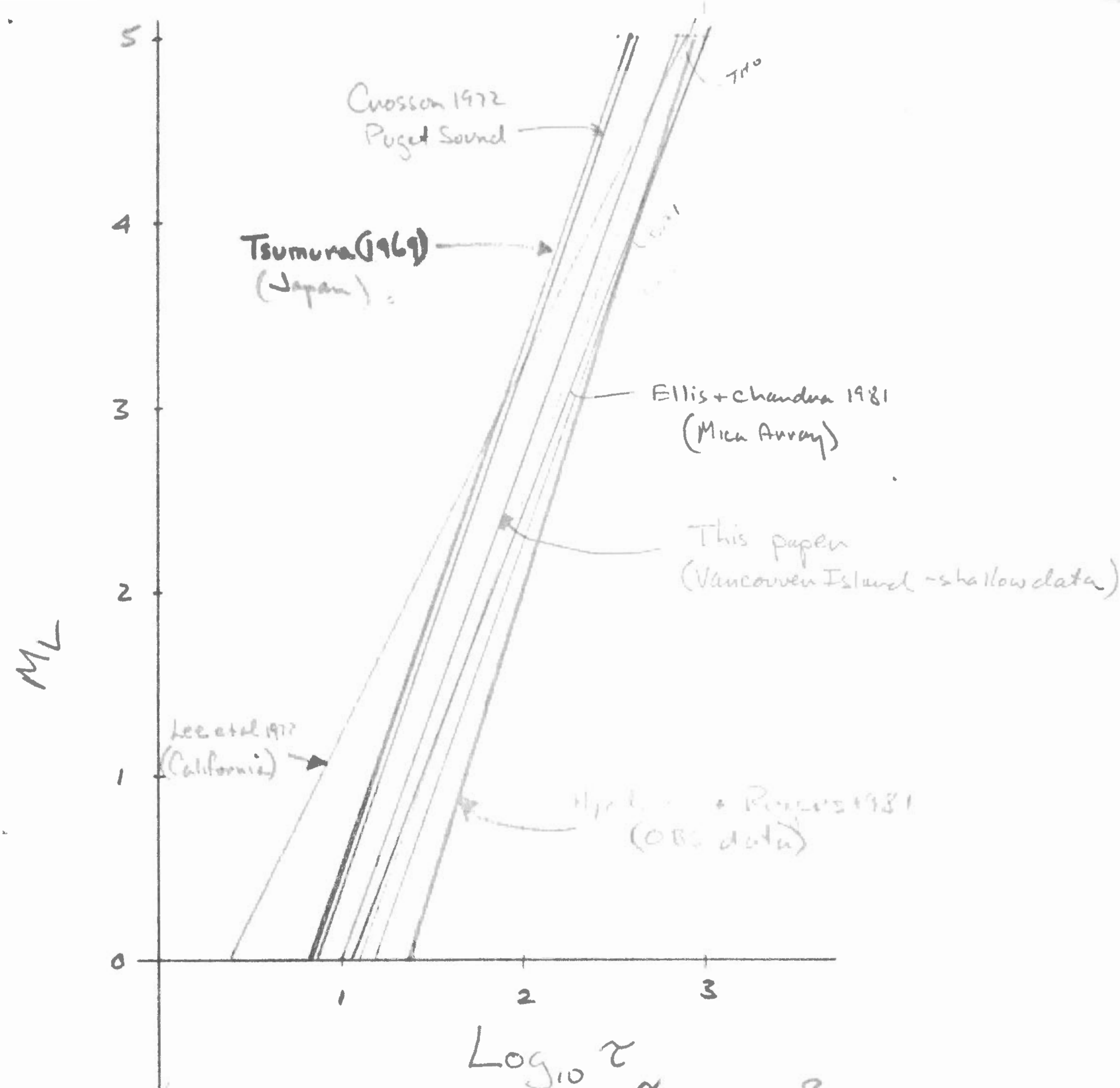


Fig. 5: Plot of M_L as published in the EPB catalogues vs log of the average codal length of all stations. All data and data shallower and deeper than 30 km is plotted.



		α	β
Tsumura		-2.37	2.85
Crosson		-2.46	2.82
This study		-2.70	2.71
Lee et al		[illegible]	2.00
Hyndman + Rogers		[illegible]	3.2
Ellis + Chandra	THO	-3.00	2.73
	DAI	-3.23	2.69
	SPR	-2.68	2.45
	CUM	-3.31	2.76
	TAB	-3.16	2.67

Fig. 6: Several M_L vs log τ relationships in the literature.

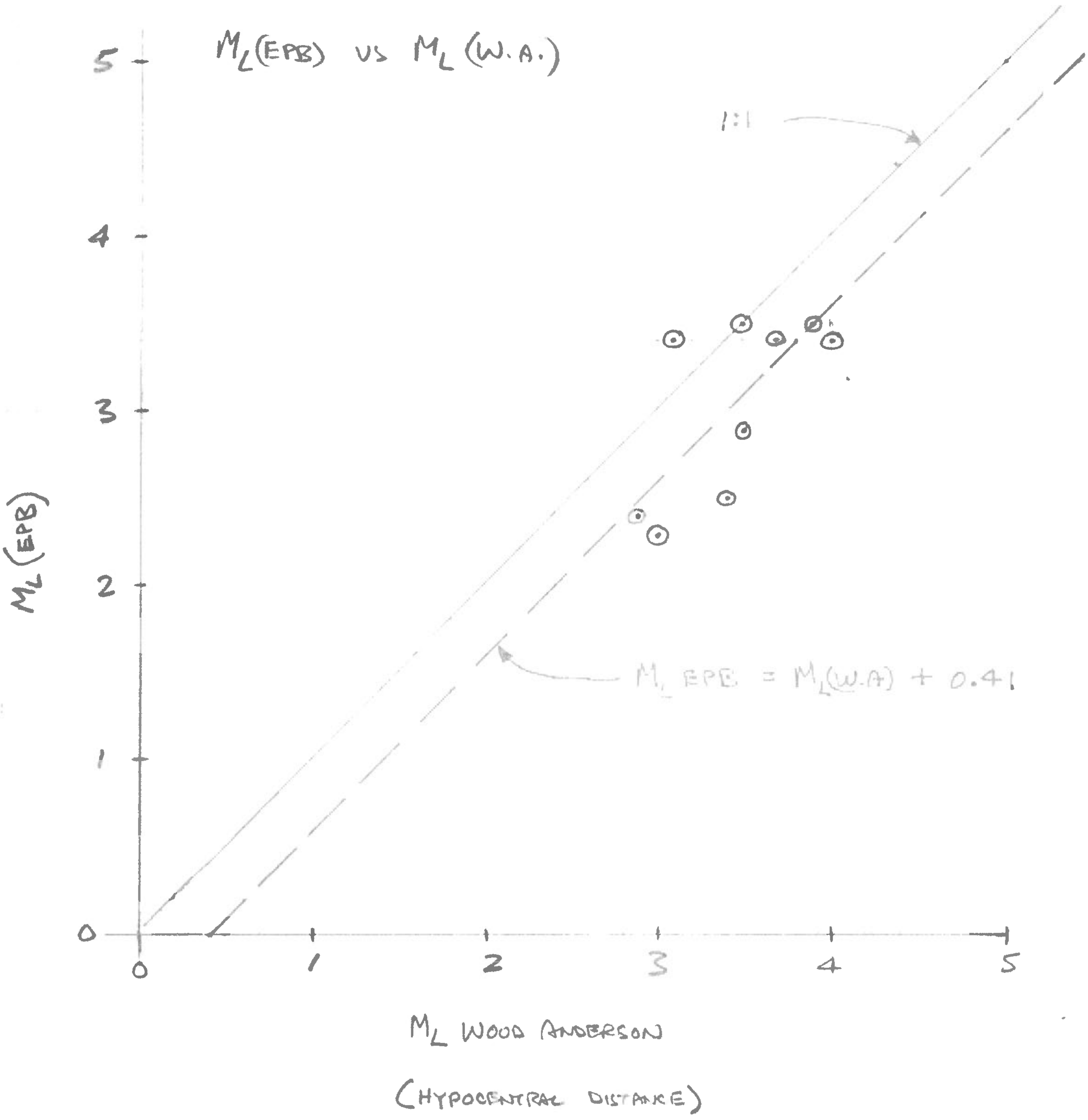


Fig. 7: Plot of M_L from the EPB catalogues vs M_L calculated from the VIC Wood Anderson seismographs using hypocentral distance in Richter's relationship. These 9 events represent the only Wood Anderson data available on microfilm for this time period.

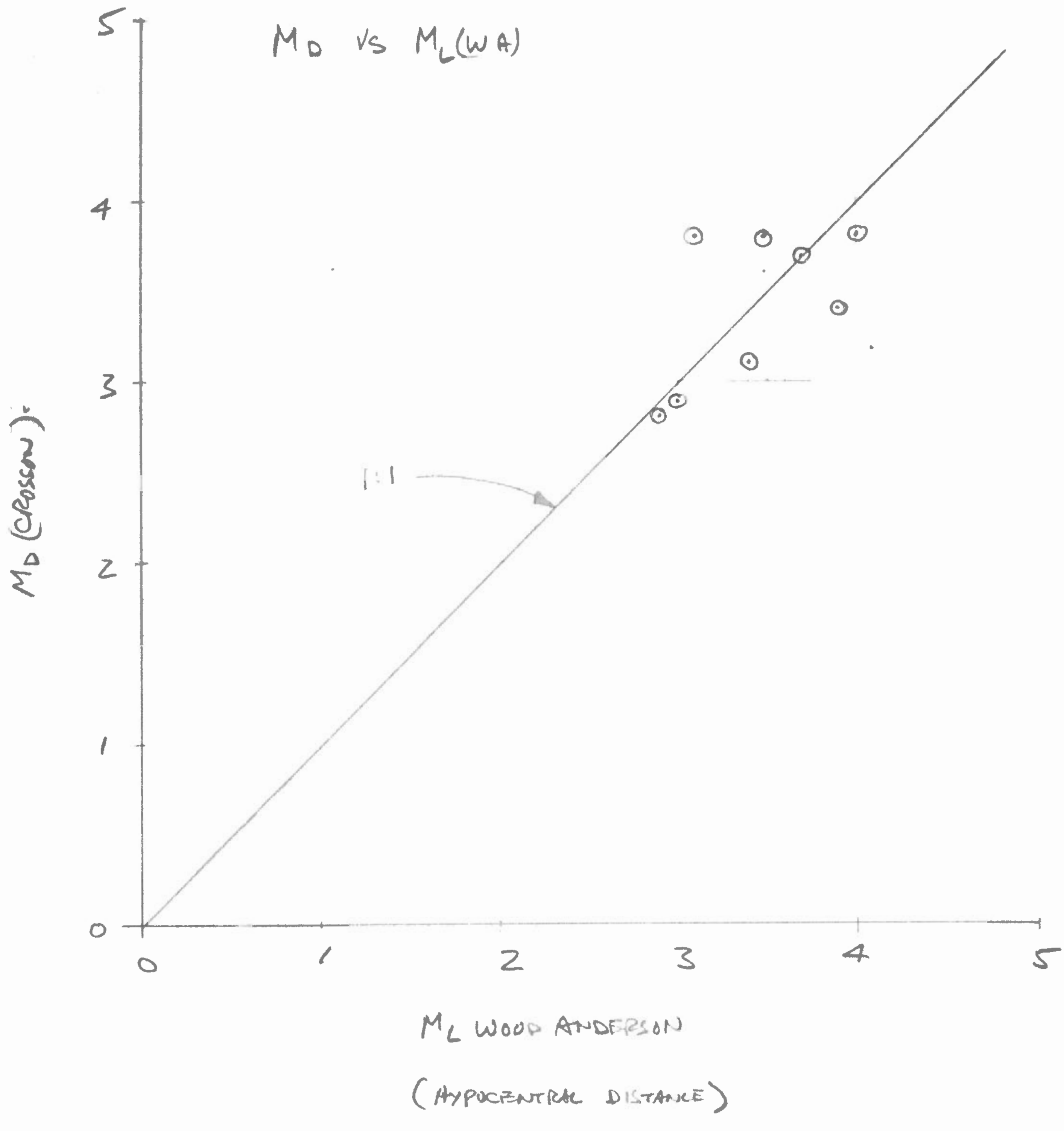


Fig. 8: Plot of M_D calculated from the average duration (using Crosson's formula) vs M_L calculated from VIC Wood Andersons for the 9 events available on microfilm.

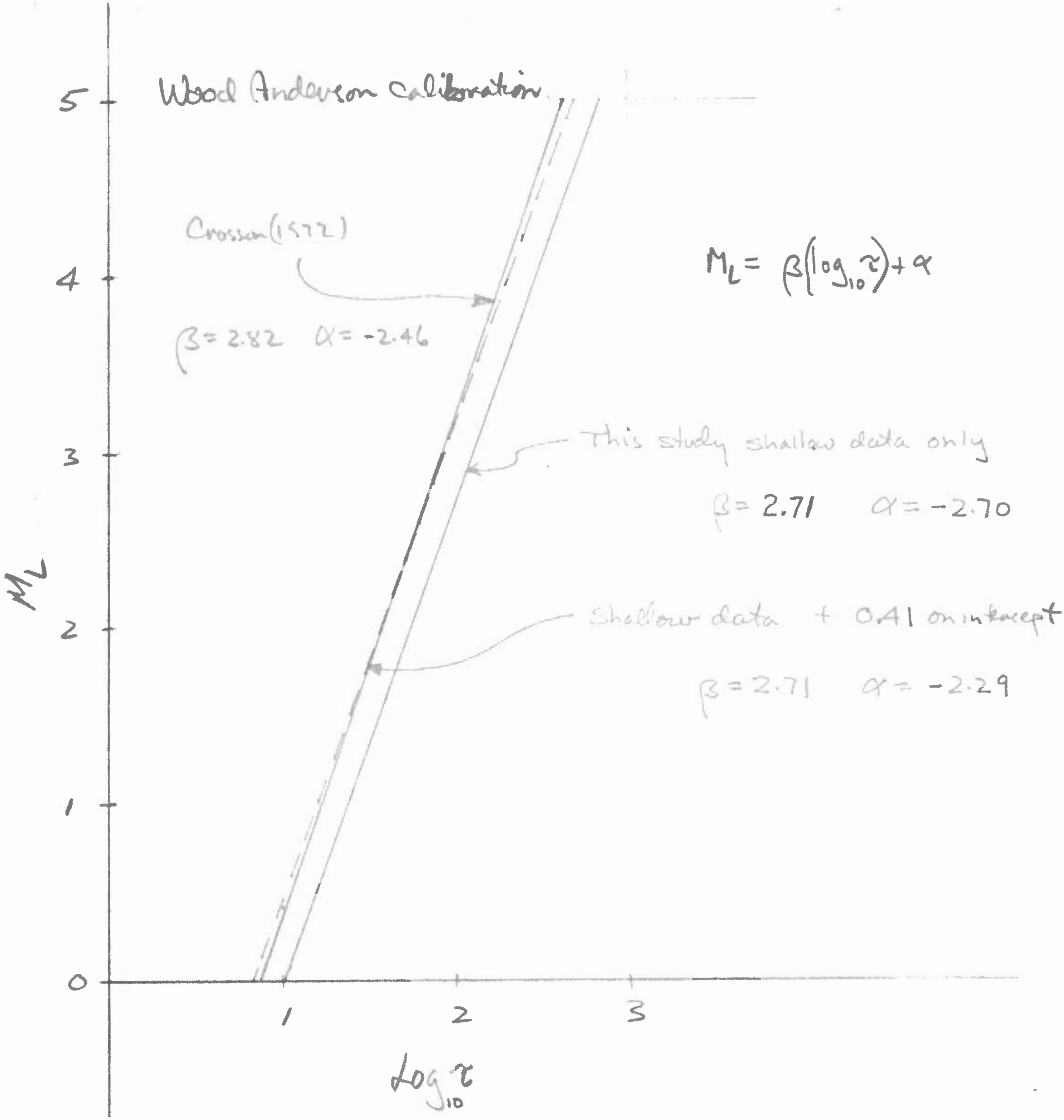


Fig. 9: Plot showing the similarity of Crosson's relationship and the relationship derived here for shallow data (Figure 5) if the average 0.41 difference between M_L values in the EPB catalogue and VIC Wood Anderson M_L values is taken into account.