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NEW EVIDENCE FOR THE EXISTENCE OF GUTENBERG'S ASTHENOSPHERE CHANNEL

by

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Abstract

New evidence for the existence of Gutenberg's asthenosphere channel is presented. The method is based on the data of distant earthquakes.

The depth of the channel is different for different earthquake regions. The critical depth, obtained in this paper, might correspond to the »trough» or minimum velocity level of Gutenberg's channel. For Alaska it is 45 km, for North Japan 80 km, for Tonga 95 km and for South America 120 km.

The results clearly demonstrate the importance of the regional study of seismograms. The possibility of misinterpretion of the focal depth of the earthquakes above 150 km is indicated and the fact strongly suggests the need to develop an accurate method for calculating the depth.

Introduction

In 1926, GUTENBERG [3] explained a phenomenon which he interpreted as due to a decrease in wave velocity at a depth of between 70 and 80 km. In a number of papers (GUTENBERG, [3, 5, 6, 7, 8, 9, 10]; GUTENBERG and RICHTER, [4, 11]), he has adduced new evidence and confirmation for the existence of this low velocity layer, later called by him the asthenosphere channel. For the depth of the channel Gutenberg gives the limits 60 and 150 km for P, and 60 and 250 km for S. P. CALOI [1, 2] has also explained and analyzed the existence of the asthenosphere channel, even contemporaneously with Gutenberg.

In Vesanen's papers [14, 15, 16] many phenomena concerning seismogram type were noted, which could now, taking the above-mentioned background into consideration, be explained and thus lend additional support to Gutenberg's hypothesis.

In the following, the authors of the present paper present a new method for establishing the existence of Gutenberg's asthenosphere channel and also for determining the depth of the channel. Ghis method is based on the data of distant earthquakes (æ about from 40° to 83°) studied regionally. All data are measured direct from the original records and for each case studied the table are used for one quantity only, $(S-P)_{surf.}$, corresponding to the epicentral distance given in the I.S.S. A great advantage is that the effect described in this paper is almost independent of epicentral distance.

Method used

With values taken from the Jeffreys—Bullen tables [13], for a given epicentral distance the difference

$$(S-P)_{surf.}-(S-P)_{h} \qquad (a)$$

was calculated for the focal depths h=0.00, 0.01, 0.02, etc., and the values obtained were compared with the corresponding values of

$$(pP-P)_{h}. \qquad (b)$$

The equation

$$(S-P)_{surf.}-(S-P)_{h}=f(pP-P)_{h} \qquad (c)$$

is given by the points representing the epicentral distances of 40°, 60° and 80°(Fig. 1). It is linear; the points lie on a straight line and they also show that the relationship is almost independent of the epicentral distance, especially when pP—P is less than 60 sec.

The function (c) is now studied with reference to the data for different earthquakes occurring at different depths in a given region. The time differences $(S-P)_h$ and $(pP-P)_h$ are measured from the records and the difference $(S-P)_{surf.}$ is the only quantity taken from the tables. The equation is now represented as follows

$$(S-P)_{J.-B.\ (surf.)}-(S-P)_{meas.}=f(pP-P)_{meas.} \qquad (d)$$

Earthquakes occurring in four different regions have been studied in this way. For the earthquakes of North Japan and Alaska the S—P and the pP—P have been measured direct from the original records

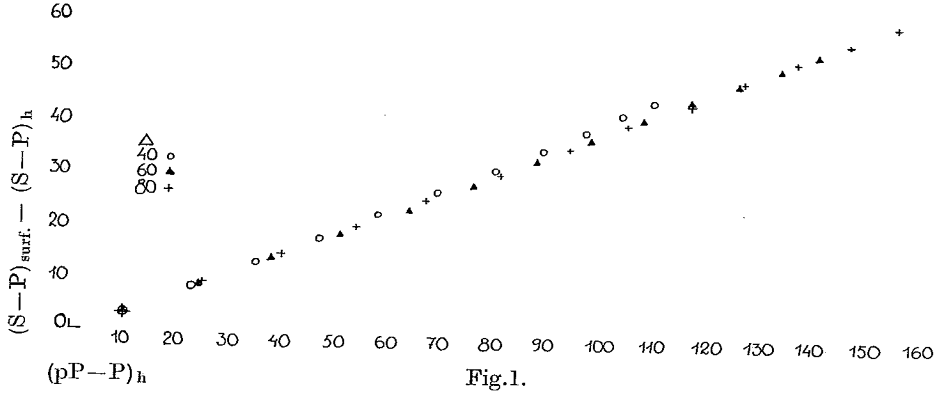

Fig. 1.

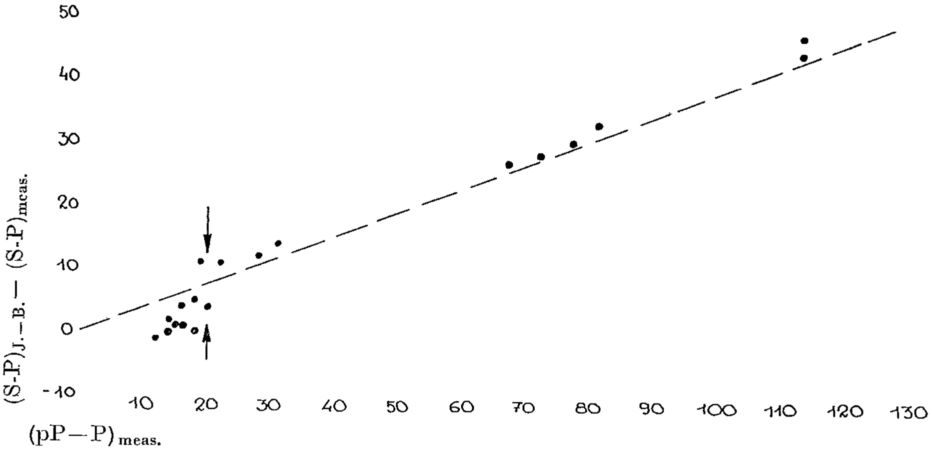

Fig. 2. (North Japan)

of Helsinki. For the $(S-P)^{surf.}$ the epicentral distances given in the I.S.S. have been used. For the Tongan and South American earthquakes, the data of Pasadena have been taken from the I.S.S.

North Japan

The original seismograms of the earthquakes occurring in North Japan and adjacent areas (1926—37), which have the most prominent P, pP and S impulses, were analyzed very carefully. The seismogram type was used as a systematic basis for determining the time of the impulses. The differences (a) and (b) were calculated (Table 1) and the corresponding points representing the function (d) were plotted in Fig. 2.

Table 1.

Date and hour	h (ISS)	Δ (ISS)	S-P (J.-B.)	S-P (meas.)	[1]	pP-P (meas.)
1926 Step. 04d 15h		64.7	8—39.8	8—40	0	18
1927 July 12d 21h	.015	65.4	8—43.8	8—32	12	28
1927 Aug. 05d 21h		68.9	9—03.9	9—00	4	16
1928 May 08d 04h	.070	61.0	8—17.9	7—34	44	113
1928 May 27d 09h		67.6	8—56.5	8—57	0	14
1930 Mar. 10d 16h	.090	61.0	8—17.9	7—31	47	113
1930 July 22d 19h	.020	65.6	8—45.1	8—31	14	31
1931 Feb. 20d 05h	.045	60.9	8—17.3	7—47	30	77
1931 Mar. 29d 17h	.010	65.9	8—46.8	8—36	11	22
1932 Sept. 03d 11h		67.0	8—53.1	8—52	1	16
1932 Sept. 23d 14h	.040	62.2	8—25.0	7—58	27	67
1932 Nov. 13d 04h	.045	62.0	8—23.8	7—56	28	72
1932 Nov. 26d 04h		65.5	8—44.8	8—40	5	18
1935 July 19d 00h		70.2	9—11.3	9—12	−1	12
1935 Sept. 11d 14h		65.6	8—45.0	8—44	1	15
1935 Oct. 02d 05h		65.6	8—45.0	8—43	2	14
1936 Nov. 02d 20h		68.8	9—03.4	8—59	4	20
1937 Apr. 29d 20h	.050	60.7	8—16.1	7—43	33	81
1937 July 26d 19h		68.9	9—03.9	8—53	11	19

For the deeper focus, the points are in very good accord, but when pP—P is smaller than 20 sec the points seem clearly to lie below the normal line, drawn according to Fig. 1. There also seems to be a considerable scatter among these points.

In other words, when pP—P is less than 20 sec, which corresponds here to a focal depth of 80 km, some changes seem to occur in the seismogram, causing difficulty in the analysis of records of earthquakes between Mohorovičić'discontinuity and 80 km depth in the region of North Japan. This seems to be connected with the existence of Gutenberg's asthenosphere channel. We should like to point out here that the

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[1] $(S\text{-}P)_{J.-B.} - (S\text{-}P)_{meas.}$

Table 2.

Date and hour	h (ISS)	Δ (ISS)	S-P (J.-B.)	S-P (meas.)	[1]	pP-P (meas.)
1927 July 28d 16h		65.1	8—42.1	8—37	5	11*)
1929 Feb. 26d 09h	.005	66.0	8—47.4	8—42	5	11*)
1929 Mar. 07d 01h	.010	69.7	9—08.5	8—57	12	21*)
1932 Aug. 12d 03h		66.7	8—51.4	8—54	—3	7
1932 Oct. 16d 12h		64.8	8—40.3	8—41	—1	10
1932 Oct. 30d 20h		64.8	8—40.3	8—41	—1	10
1934 May 04d 04h		58.2	8—01.0	8—00	1	12*)
1934 May 14d 22h		61.6	8—21.4	8—20	1	11*)
1934 July 28d 21h		64.2	8—36.9	8—38	—1	10
1937 Apr. 29d 18h		65.4	8—43.8	8—41	3	12*)
1938 Nov. 10d 20h		64.2	8—36.9	8—37	0	10
1938 Nov. 11d 00h		64.2	8—36.9	8—41	—4	10
1938 Nov. 17d 03h		64.2	8—36.9	8—39	—2	11

seismogram type also changes within the same depth range, between 70 and 80 km (cf. VESANEN, [14, 15]) .For the focal depths below 80 km the points lie slightly above the normal line. This might be explained by assuming that the depth of the channel for the P is different from that for the S, a conclusion reached by GUTENBERG [9]. It may be mentioned that a corresponding phenomenon was noted out by VESANEN [14, 15] regarding the type of the seismogram: the depth of focus which affects the seismogram type seems to be different for the P and for the S.

Alaska

In the Alaska region there occur only normal and intermediate shocks. The special analyses made for another paper (VESANEN, [16]) were used for this investigation and are given in the following table (Table 2).

The function investigated in this paper follows the same course as before (Fig. 3). The critical value of the pP—P is different here, however, and seems to be only 12 sec. Unfortunately, there are only a couple of

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[1] $(S\text{-}P)_{J.-B.} - (S\text{-}P)_{meas.}$

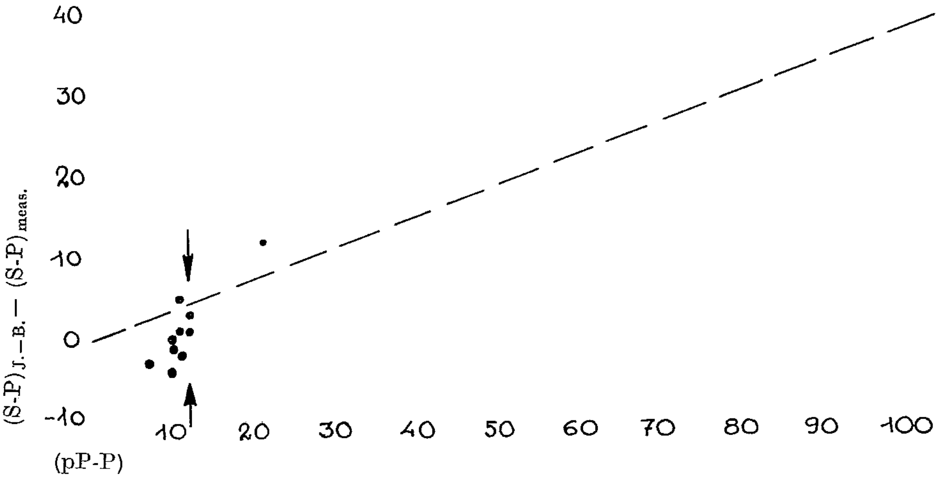

Fig. 3. (Alaska)

shocks included in our material which are deeper than normal, according to the I.S.S., but nevertheless the effect under discussion is clear. Regarding this region it has been pointed out earlier (VESANEN, [16]) that in certain cases the measured values of the pP—P seem to be too small, which was explained by suggesting that the phase identified as »pP» is in fact the corresponding impulse reflected from Mohorovicic's discontinuity. This interpretation is indicated for the cases marked with an asterisk in Table 2. The corresponding points (Fig. 3) should thus be poltted about 5—10 sec to the right. This move, however, does not affect the course of the function. Here the critical depth should be only about 45 km. With regard to the seismogram type of this region, VESANEN [14] pointed out that the features characteristic of deep focus seismograms typically appear here even on normal seismograms, — in other words, that the factors responsible for these effects exist closer to the earth's surface here than in other regions.

Tonga

To eliminate any possibility that the effect under discussion might be due to unusual characteristics of the seismogram material of Helsinki or to its analysis, the earthquakes in the Tonga region in the years 1933—1950 were investigated from the data of Pasadena as given in the I.S.S. Pasadena is located at a distance of 70°—80° from the Tonga

Table 3.

Date and hour	h		Data of Pasadena taken from ISS				2)	pP-P
	(ISS)	(G.-R.)1)	Δ	P	S	pP		
1933 Sept. 06d 22h	.075	600	79.8	i11—18	i20—44	i13—25	37	127
1934 Oct. 10d 15h	.080	540	81.5	i11—26	i20—58	i13—26	41	120
1935 Jan. 01d 13h		300	73.9	i11—03	i20—12	i12—21	23	78
1935 July 29d 07h	.060	510	78.5	i11—22	i20—51	i13—16	27	114
1937 Apr. 16d 03h	3)	400	78.3	e11—33	e21—02	i12—10	26	97
1939 June 08d 20h	.010	100	72.5	i11—18	e20—30	i11—44	10	26
1939 July 20d 02h	.080	650	80.5	i11—17	i20—35	e13—27	49	130
1944 May 25d 01h	.080	640	80.0	i11—15	i20—35	i13—23	44	128
1945 Nov. 26d 05h	.090	600	80.7	i11—14	e20—34	e13—18	47	124
1946 Aug. 21d 18h	.010	100	80.8	i12—05	i22—10	i12—30	3	25
1946 Sept. 26d 10h	.090	600	84.4	i11—32	i21—03	i13—36	53	131
1948 Jan. 04d 08h	.080	600	79.4	i11—10	i20—28	i13—12	43	122
1948 Jan. 22d 13h	.010	140	79.5	i11—56	i21—43	i12—31	13	35
1948 June 29d 10h		60	71.3	i11—23	i20—39	i11—47	4	24
1948 Sept. 08d 15h			76.3	i11—51	i21—36	i12—02	—1	1
1949 Jan. 24d 09h	.015	110	78.6	i11—48	i21—39	e12—39	6	25
1949 July 27d 15h		70	83.3	i12—28	i22—46	i12—47	2	19
1949 Aug. 06d 00h	.005	70	75.1	i11—36	i21—14	i11—53	0	17
1949 Nov. 27d 08h		60	73.6	i11—37	e21—04	i11—55	—3	18
1949 Dec. 20d 04h	.090		80.7	i11—07	i20—35	i13—19	39	132
1950 Jan. 12d 12h	.080		77.3	i11—00	i20—07	e12—56	43	116
1950 Mar. 16d 19h	.080		77.3	i10—59	i20—06	i13—00	43	121
1950 May 27d 14h	.090		77.3	i10—55	i20—00	i12—57	45	122
1950 May 30d 15h	.080		79.0	i11—06	i20—22	i13—12	43	126
1950 July 27d 17h	.080		77.4	i11—00	e20—01	e13—00	49	120
1950 Aug. 17d 16h	.090		80.7	i11—14	e20—24	i13—21	57	127

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1) Gutenberg and Richter, [1954].

2) $(S\text{-}P)_{J.-B.} - (S\text{-}P)_{Pasadena}$

3) I.S.S.: Wellington 250 km, JSA 390 km, USSR 600 km, USCGS 400 km.

Table 4.

Date and hour	h		Data of Pasadena taken from ISS				[2])	pP-P
	(ISS)	(G.-R.)[1])	Δ	P	S	pP		
1944 Feb. 29d 03h	.015	200	66.2	i10—34	i19—10	i11—21	12	47
1944 June 08d 02h	.080	600	62.0	i09—29	e17—13	e11—27	40	118
1944 Dec. 22d 22h		120	75.2	i11—41	i21—19	i12—10	1	29
1945 May 01d 16h	.010		80.3	i12—00	i21—57	i12—31	8	31
1945 June 24d 19h	.010		82.0	i12—11	i22—19	i12—36	6	25
1945 Aug. 01d 11h	.080		63.0	i09—34	i17—20	i11—36	4	122
1945 Dec. 14d 17h	.015		53.6	i09—11	i16—36	i09—38	8	27
1946 Aug. 28d 22h	.090	580	79.6	i11—07	i20—24	i13—07	44	120
1946 Sept. 30d 00h	.005	70	61.7	i10—17	i18—42	i10—37	—3	20
1946 Oct. 13d 23h	.025	200±	75.4	i11—23	i20—46	e12—20	18	57
1947 Jan. 29d 08h	.080	580	79.5	i11—13	e20—29	i13—16	46	123
1947 July 25d 19h	.080	580	78.4	i11—05	i20—17	i13—08	44	123
1947 Aug. 06d 05h	.090	600	62.0	i09—23	i17—00	i11—19	47	116
1949 Mar. 13d 18h	.005		73.0	i11—22	i20—42	i11—51	7	29
1949 Apr. 17d 00h	.005		80.3	i12—06	i21—59	i12—35	12	29
1949 Apr. 20d 03h		70	83.3	i12—25	i22—42	i12—41	4	16
1949 Apr. 25d 13h	.005	110	70.7	i11—12	i20—24	i11—40	2	28
1949 May 08d 21h	.015		71.9	i11—12	i20—24	i11—42	9	30
1949 May 30d 01h	.010		71.9	i11—16	i20—33	i11—42	4	26
1949 June 12d 17h	.090	620	80.6	i11—14	i20—33	e13—18	48	124
1949 Dec. 21d 19h	.090	620	74.2	i10—38	i19—23	i12—42	49	124
1950 Jan. 21d 14h	.005		71.5	i12—15	i22—23	i12—34	7	19
1950 July 09d 04h	.100	650	61.4	i09—16	i16—50	e11—27	46	131
1950 July 09d 04h	.100	650	61.4	i09—15	i16—47	i11—17	48	122
1950 Aug. 14d 22h	.090	630	80.6	i11—13	i20—31	i13—22	49	129
1950 Spet. 18d 19h	.090		61.4	i09—19	e16—56	i11—23	43	124

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[1]) Gutenberg and Richter, [1954].

[2]) $(S\text{-}P)_{\mathrm{J.-B.}} - (S\text{-}P)_{\mathrm{Pasadena}}$

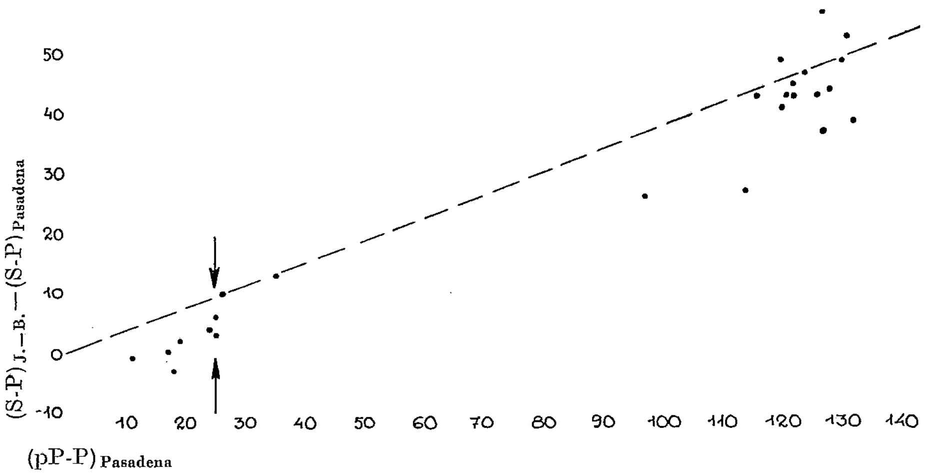

Fig. 4. (Tonga)

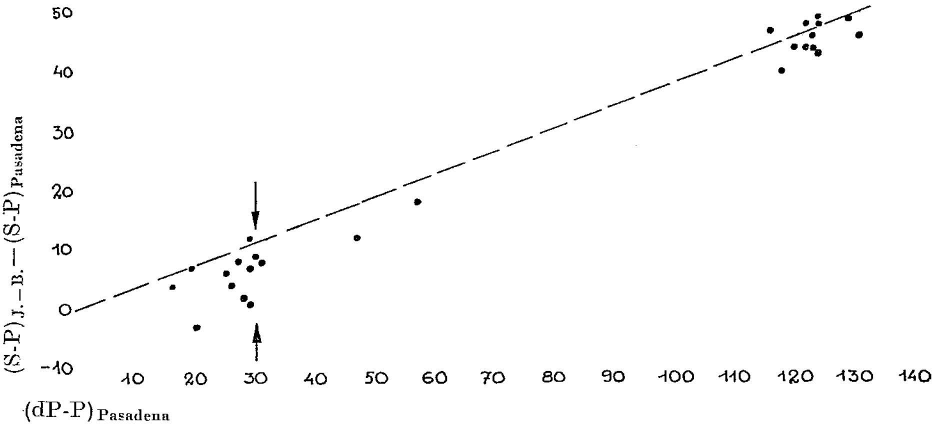

Fig. 5. (South America)

region. The data used are given in Table 3 and the results are presented in Fig. 4.

The same effect as before is very cleraly evident, and the critical depth for this region is 95 km.

South America

For this region the data of Pasaden given in the I.S.S. (Table 4) have been used. Here again, the function shows the same course as before (Fig. 5), the critical depth being as great as 120 km.

Discussion

The phenomenon described above is so clear in the four different regions that there can be no doubt regarding its existence. The carefully made personal analysis and the high-quality data of Pasadena, taken from the I.S.S., both confirm the conclusion: The critical depth is well established and is different for different regions. This is also in good accord with the investigations concerning seismogram type (VESANEN, [14, 15, 16]). There is no doubt, either, that the phenomenon is related to Gutenberg's asthenosphere channel. The different values for the critical depth obtained in this investigation are within the limits given by him. For Alaska the critical depth is smallest, only 45 km, for North Japan it is 80 km, for Tonga 95 km and for South America 120 km.

The irregular disposition of the points above the critical depth in the figures suggests that at least some of these earthquakes originate in a layer having abnormal propagation characteristics. The upper part of Gutenberg's asthenosphere channel forms an »inversion layer» where the wave velocity decreases with depth. It might be suggested that the critical depth defined in this investigation corresponds to the »trough» or minimum velocity level of Gutenberg's channel.

On the other hand, it is generally assumed that the horizontal strain in the mantle gradually changes from compressive to tensile type at a depth of about 100 km (JEFFREYS, [12]). This change should have an effect on the elastic properties of the material and might provide at least a contributory cause for the existence of the asthenosphere channel, in addition to the temperature effects suggested by GUTENBERG [10].

If the level of no horizontal strain did indeed lie somewhat below the critical depth, this would afford an explanation for the abrupt decrease in earthquake frequency at this depth. Moreover, the changes in seismogram type occurring at this depth (VESANEN, [14]) could be explained.

The results very clearly demonstrate the importance of the regional study of seismograms. If, for instance, function (d) were studied generally — not regionally — the scatter of the points would be so great that it would be impossible to draw any conclusions regarding the existence of a critical depth such as is inferred in this paper.

The need to develop accurate methods for calculating the focal depth between Mohorovičić's discontinuity and depths of about 150 km is also strongly emphasized.

Acknowledgement: The financial assistance given by the State Committee on Natural Sciences (Valtion Luonnontieteellinen Toimikunta) is gratefully acknowledged.

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ERRATA

In Volume 7, Number 1 in the article »New evidence for the existence of Gutenberg's asthenosphere channel» by E. VESANEN, M. NURMIA and M. T. PORKKA, the following corrections should be made:

page 2,	line 7,		change	Ghis	to	this,
» ,	» 8,		»	æ	»	Δ,
» ,	» 10,		»	table	»	tables
page 3,	» 1,		»	$(S-P)^{surf}$	»	(S−P)surf.,
» 4,	» 8,		»	Mohorovičić'	»	Mohorovičić,
» 6,	» 6,		»	»	»	» ,
» ,	» 9,		»	poltted	»	plotted,
page 7,	table 3,	line 2,	change	81.5	to	81.7,
» ,	» ,	» 5,	»	i12−10	»	i13−10
» ,	» ,	» 6,	»	72.5	»	72.3,
» ,	» ,	» 7,	»	80.5	»	80.7,
» ,	» ,	» 13,	»	79.5	»	79.2,
» ,	» ,	» 15,	»	1	»	11,
page 8,	table 4,	line 6,	»	4	»	44,
» ,	» ,	» 11,	»	79.5	»	79.6,
page 9,	Fig. 5,		»	(dP−P)Pasadena	»	(pP−P)Pasadena,
» ,	line 3,		change	cleraly	to	clearly,
» ,	» 6,		»	Pasaden	»	Pasadena.