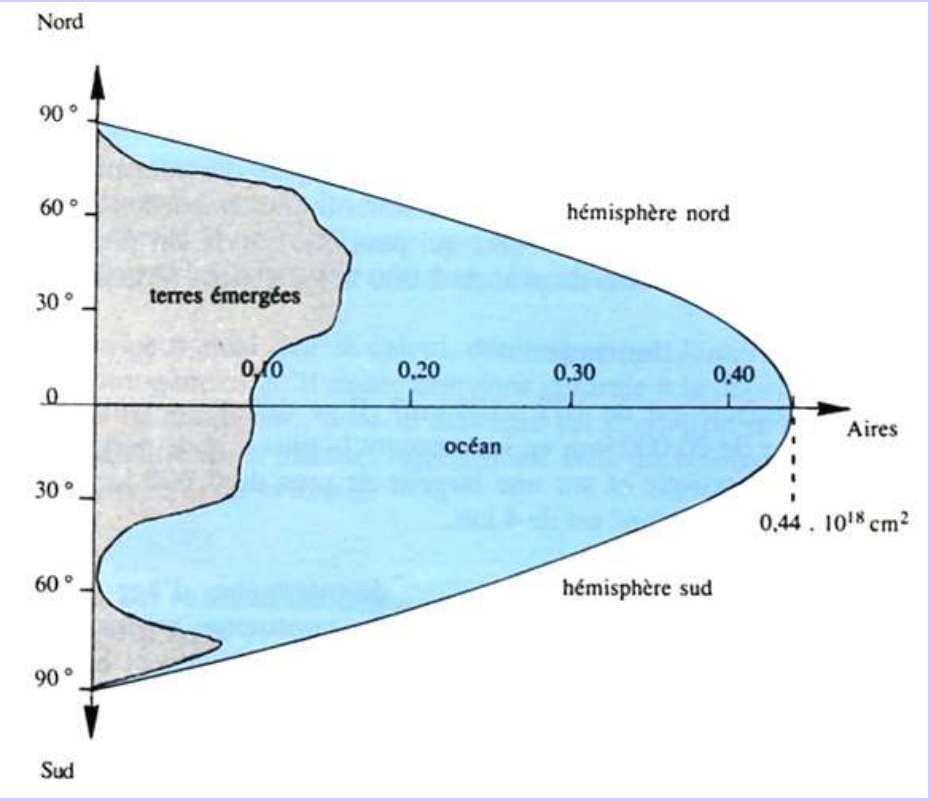
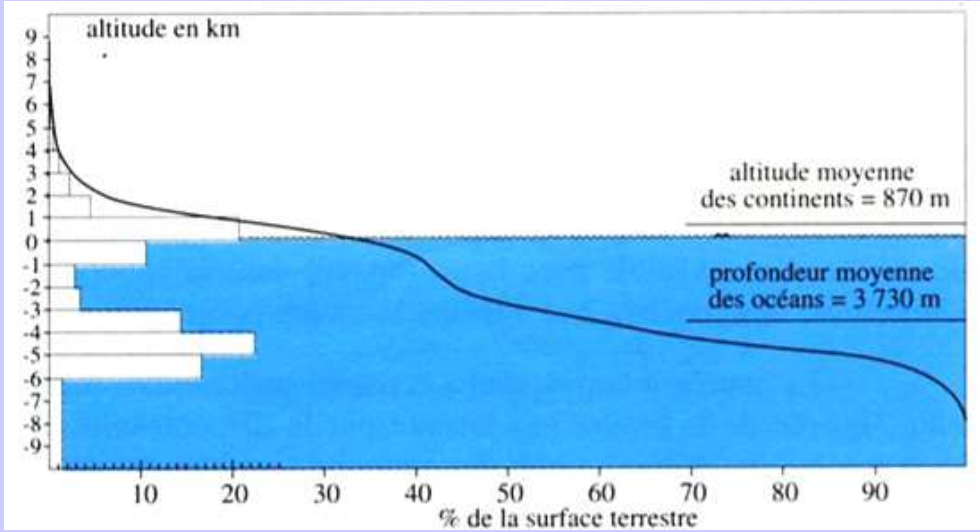
TP : La structure de la planète Terre

Document 1. Océans et continents



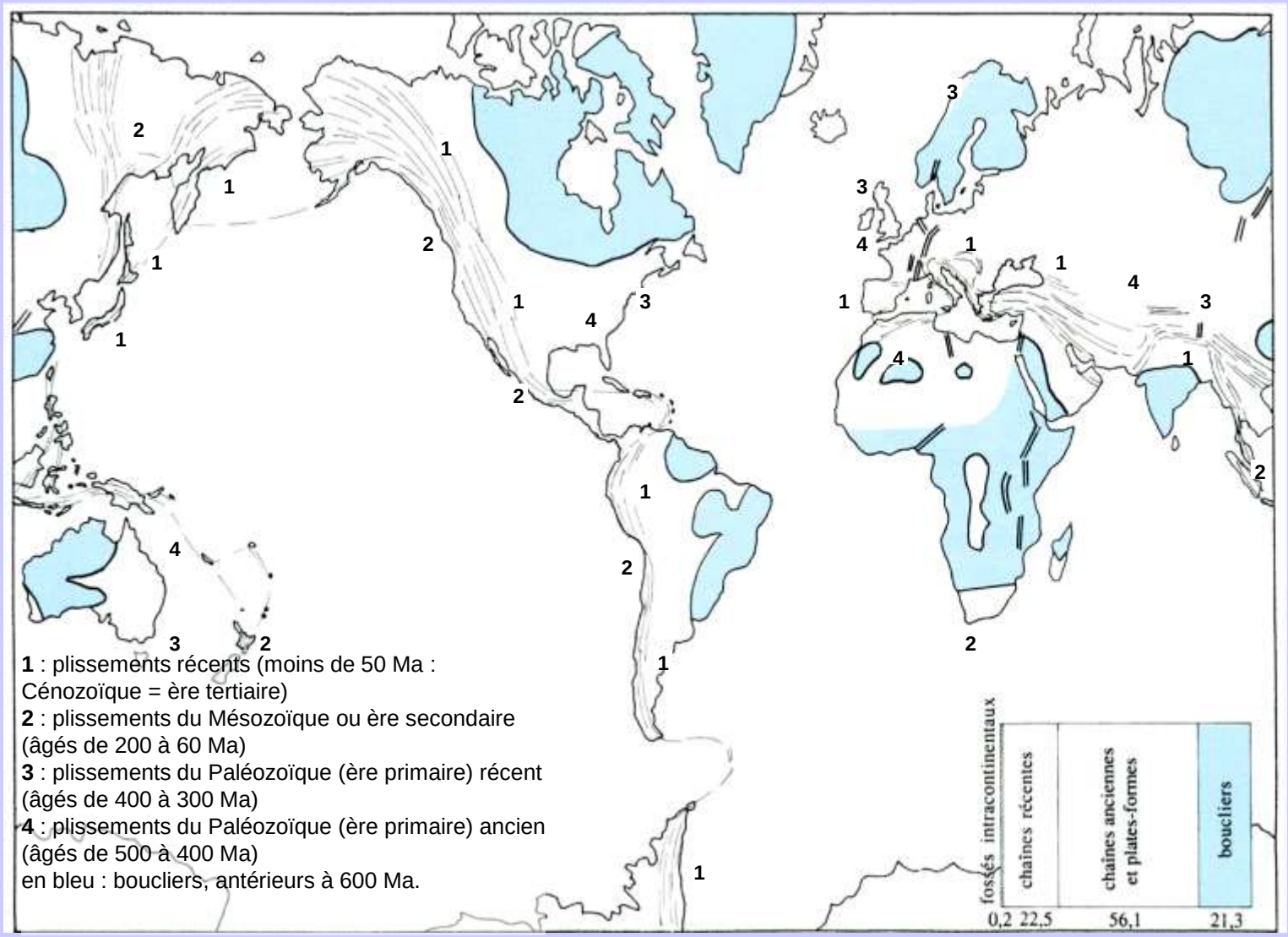
Répartition des superficies des océans et des terres émergées par hémisphère et par “ tranches ” de latitude.



Répartition des altitudes et des profondeurs sur le globe (histogramme et courbes cumulées).

“ Comprendre et enseigner la Planète Terre ”, Caron et coll. Ophrys Ed.

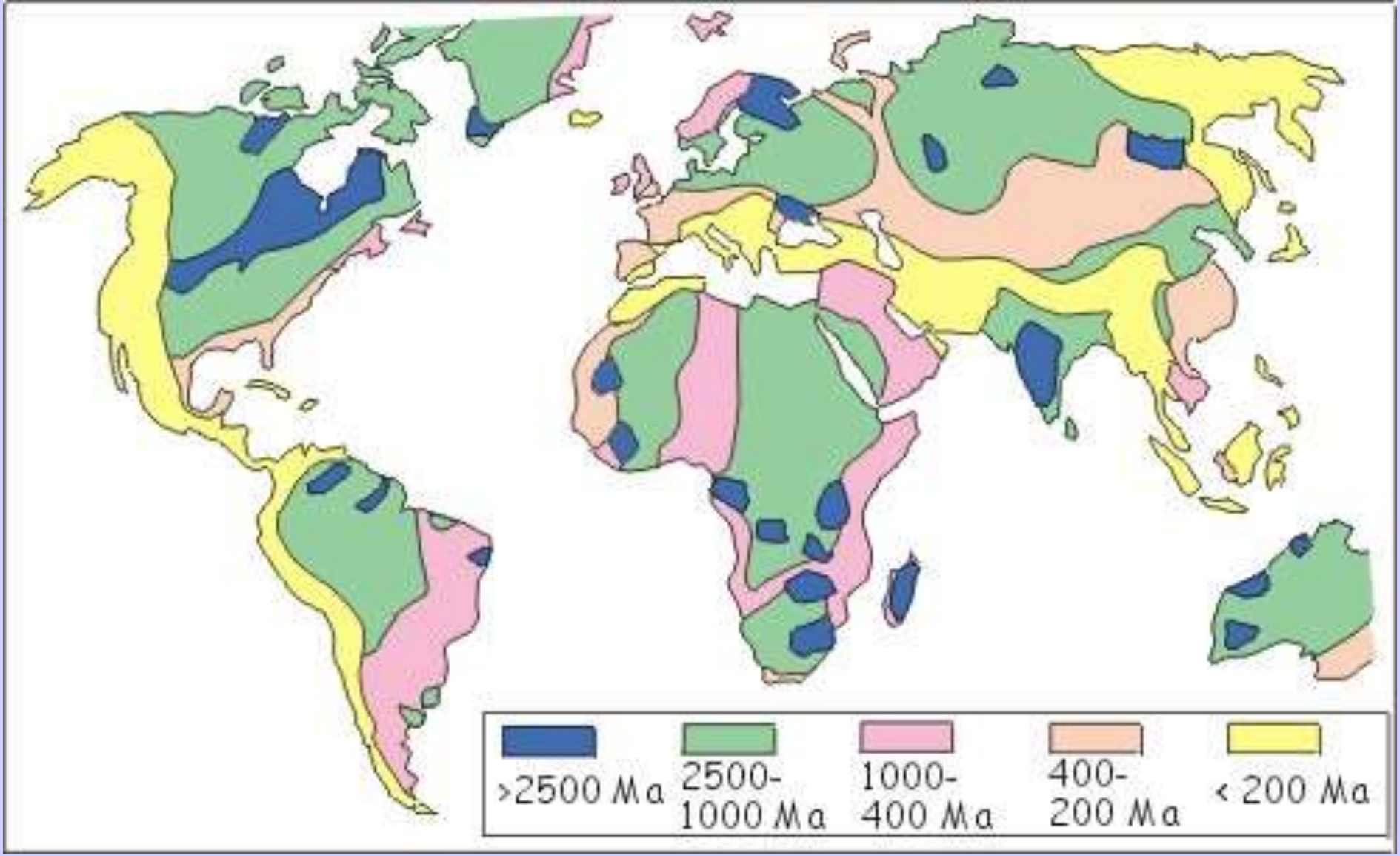
Document 2. Principaux ensembles structuraux mondiaux.



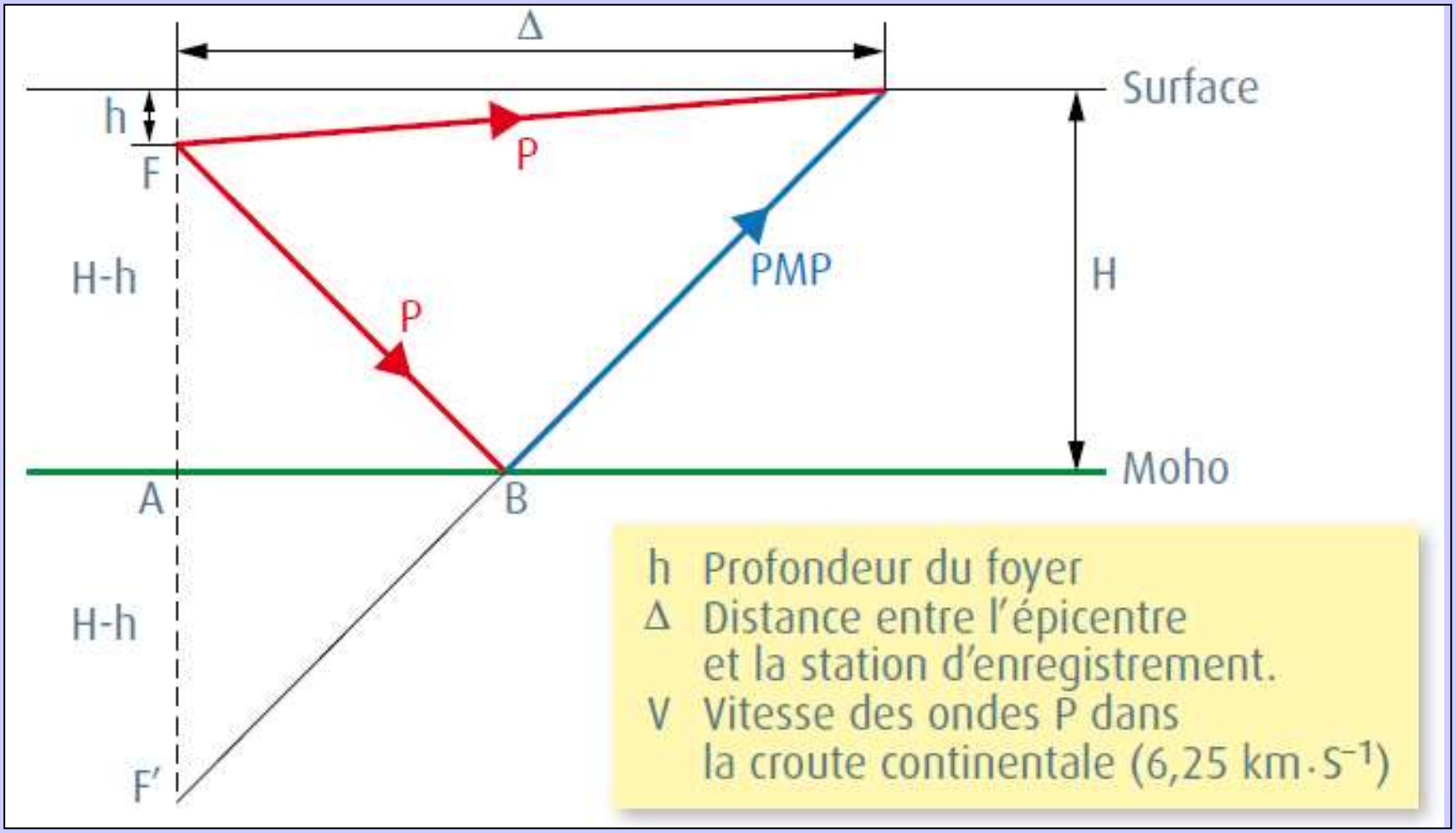
Boucliers (en bleu), plates-formes et chaînes anciennes (en blanc), chaînes récentes post-paléozoïque (tirets), fossés continentaux (double trait).

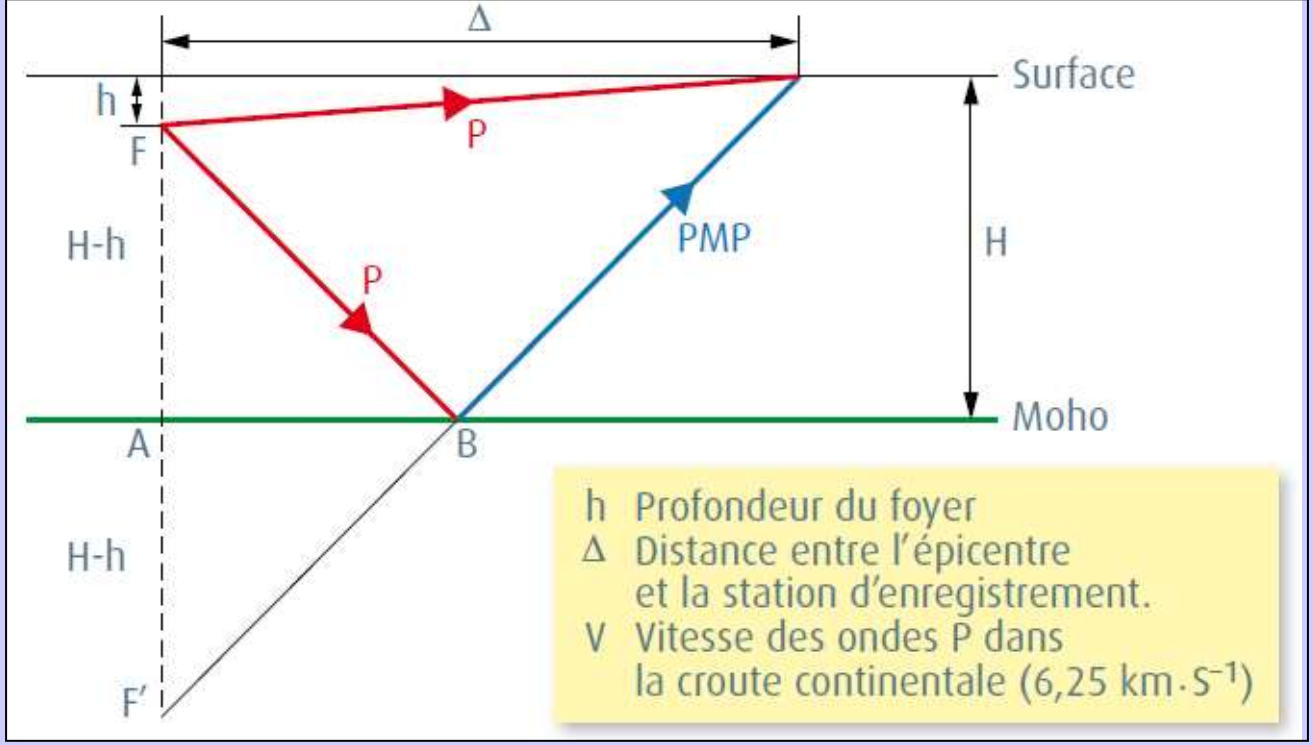
En cartouche, proportions en surface de ces différents ensembles.

(“ Géologie : objets et méthodes ”, J. Dercourt et J. Paquet, Dunod Ed.).



Document 3. Carte de l'âge de la croûte continentale.


Δ
Surface
h
F
P
H-h
PMP
H
P
Moho
A
B
H-h
F'
h Profondeur du foyer
Δ Distance entre l'épicentre et la station d'enregistrement.
V Vitesse des ondes P dans la croute continentale (6,25 km·S⁻¹)



Triangle FES : $h^2 + \Delta^2 = d^2 \rightarrow d = \sqrt{h^2 + \Delta^2}$

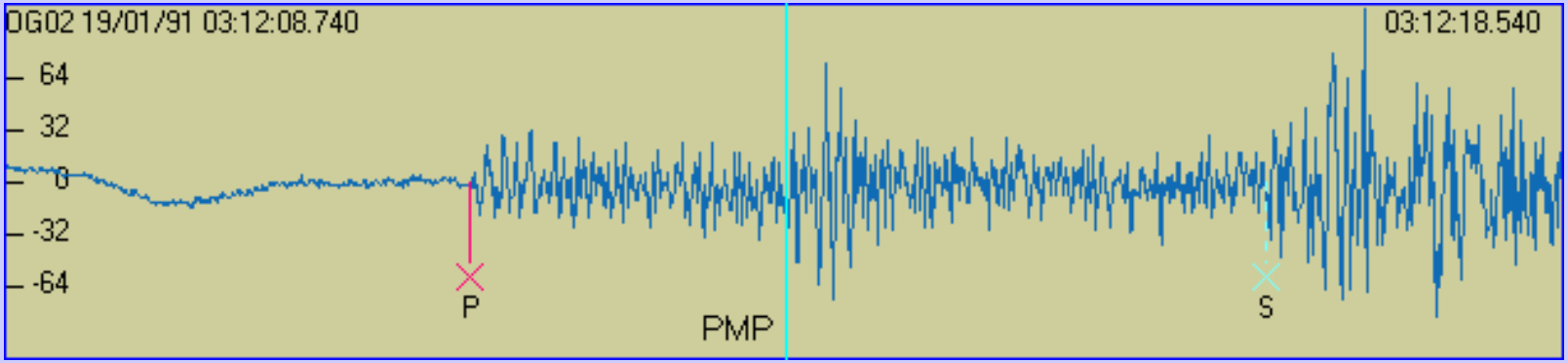
Triangle F'ES : $(2H-h)^2 + \Delta^2 = (d+v\delta t)^2$

D'où : $2H-h = \sqrt{(d+v\delta t)^2 - \Delta^2} = \sqrt{(\sqrt{h^2 + \Delta^2}+v\delta t)^2 - \Delta^2}$

Et : $\mathbf{H = \frac{1}{2}\left[h + \sqrt{(\sqrt{h^2 + \Delta^2}+v\delta t)^2 - \Delta^2} \right]}$

Mise en évidence et localisation du MOHO

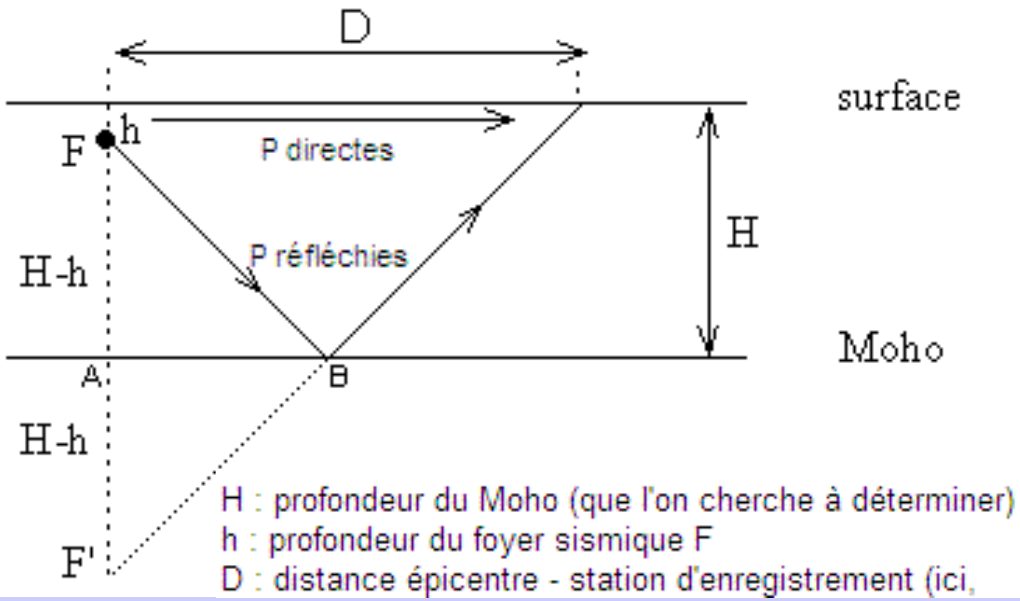
Mohorovicic, 1909



Séisme du 19/01/1991. Sismogramme reçu par la station OG02 (Annemasse).

Profondeur focale h = 11 km.
Distance épicentrale 63,3 km.
Arrivée des ondes P à 3 h 12 min 15,580 s.
Arrivée des ondes PMP à 3 h 12 min 18,540 s.
Arrivée des ondes S à 3 h 12 min 23,080 s.

$$H = \frac{1}{2}\left[h + \sqrt{\left(V.dt + \sqrt{h^2 + D^2}\right)^2 - D^2}\right]$$



NB : dans cette formule :

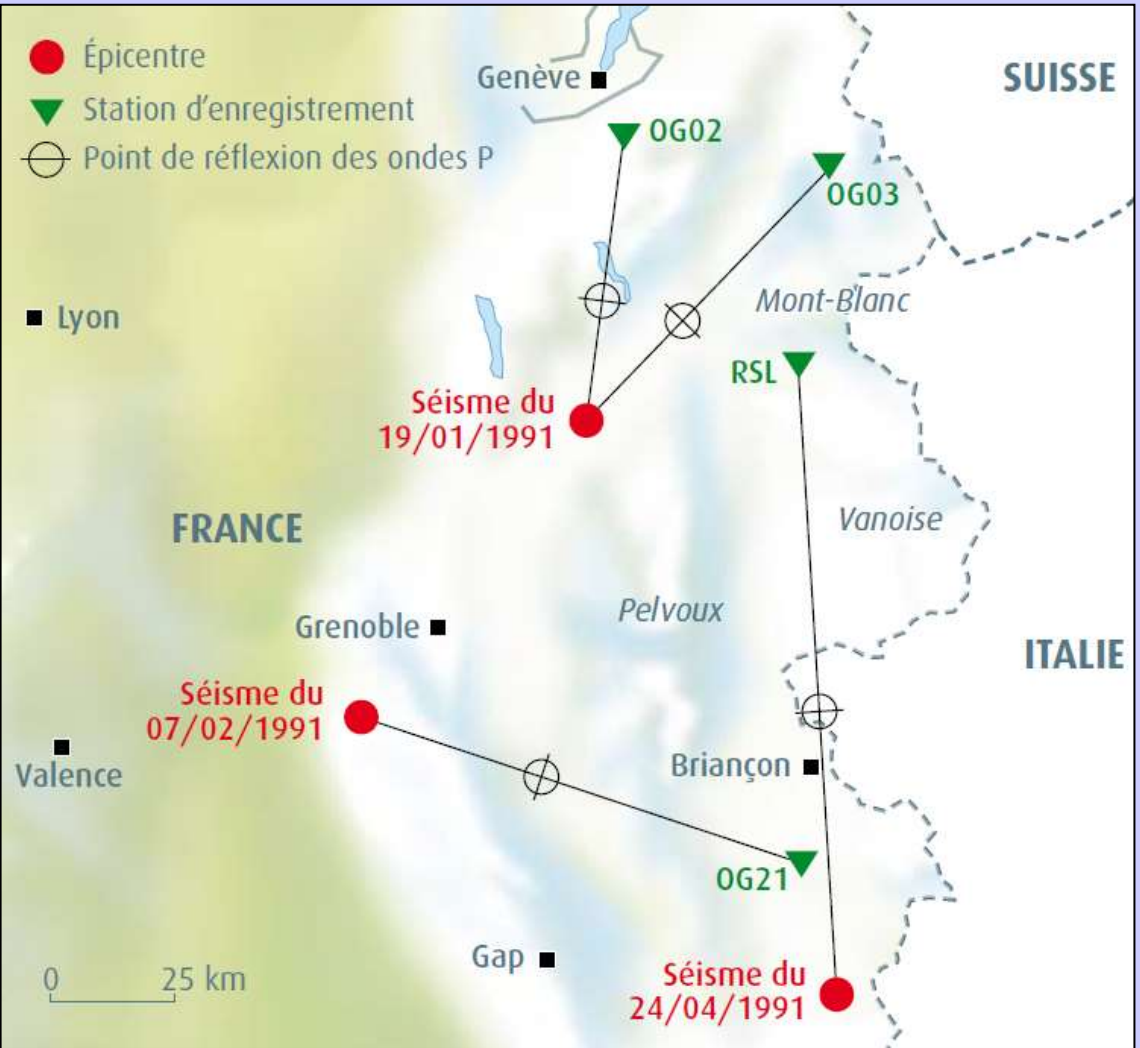
- h négligée si le séisme est relativement superficiel
- V = vitesse de propagation des ondes P à travers la croûte terrestre (ici 6,25 km/s)
- dt établi par lecture du sismogramme
- D distance épicentre - station d ’enregistrement

$$H = 1/2\ \sqrt{[(Vdt + D)^2 - D^2]}$$

Station d'enregistrement	Profondeur du foyer h	Date du séisme	Distance épicentrale	Arrivée des ondes P	Arrivée des ondes PMP
OG02 (Annemasse)	11 km	19/01/1991	63,3 km	3 h 12 min 15,580 s	3 h 12 min 18,540 s
OG03 (Samoëns)	11 km	19/01/1991	70,8 km	3 h 12 min 16,493 s	3 h 12 min 19,583 s
OG21 (Guillestre)	11 km	07/02/1991	86,4 km	4 h 48 min 21,534 s	4 h 48 min 24,874 s
RSL (Roselend)	10 km	23/04/1991	135,8 km	5 h 53 min 02,005 s	5 h 53 min 05,325 s

h

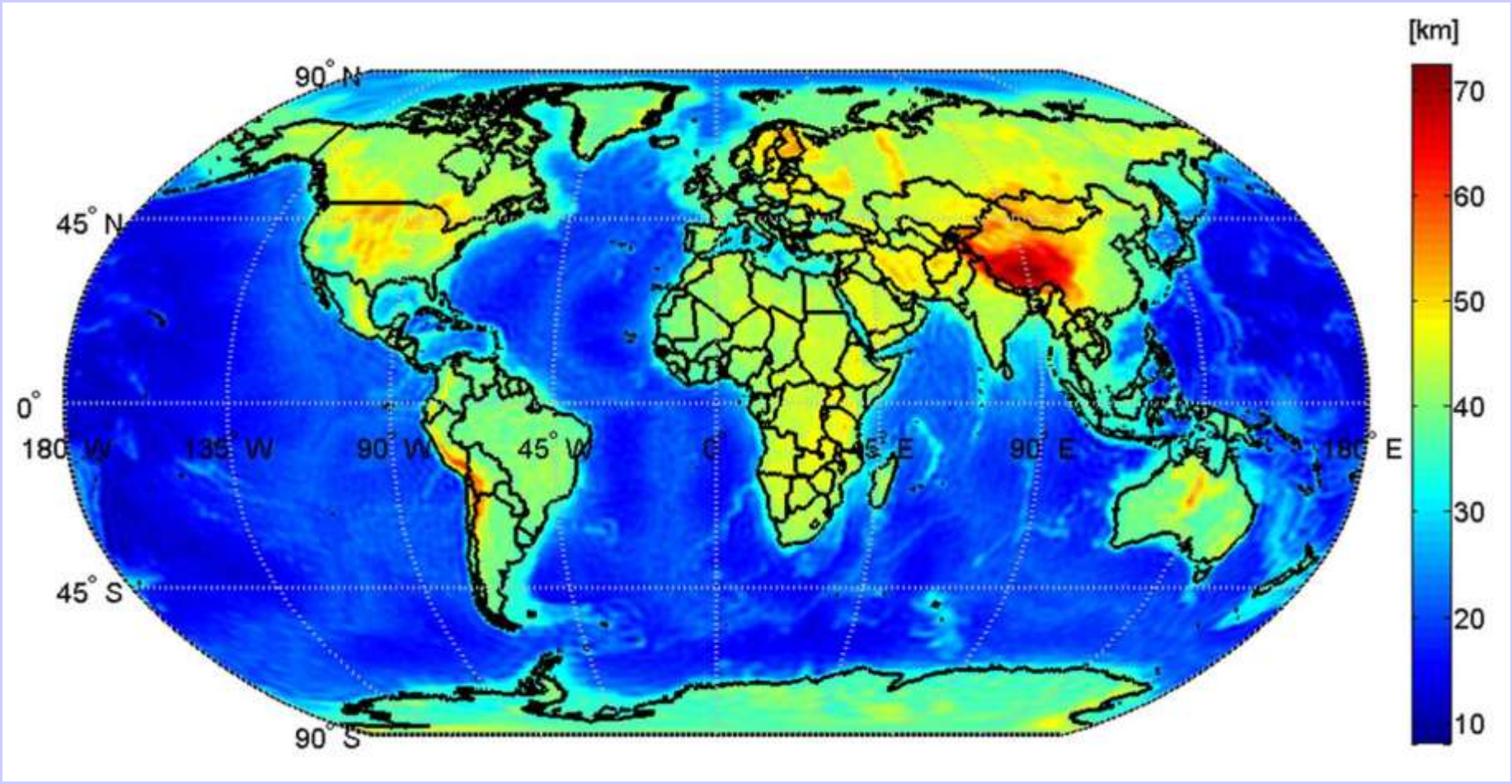
Δ

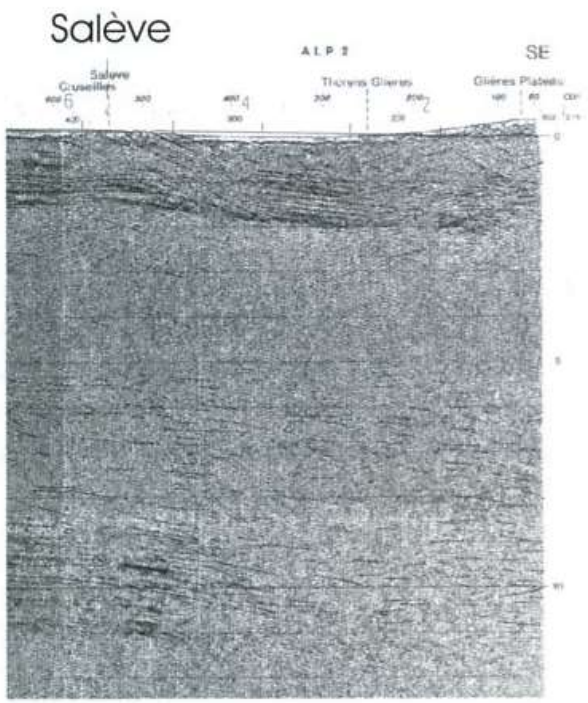


Station	δt
OG02	2,96
OG03	3,09
OG21	3,34
RSL	3,32

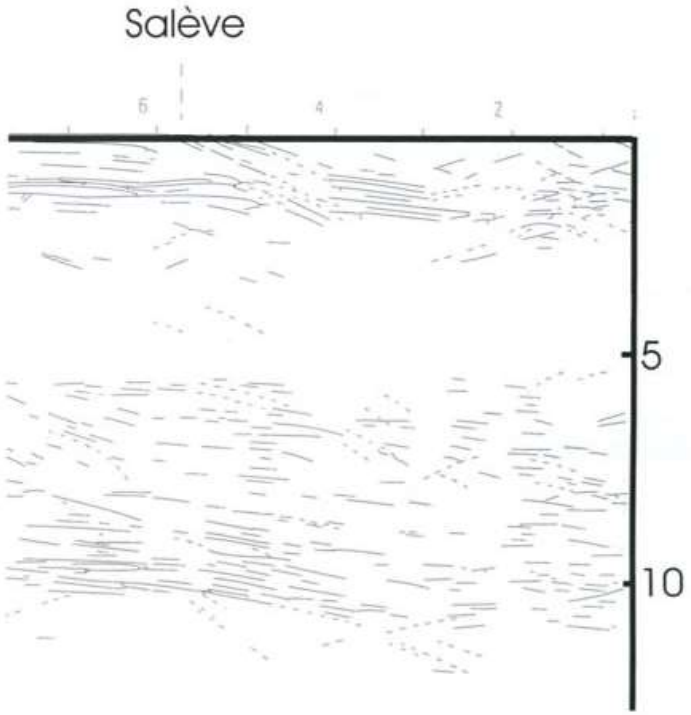
$Vp = 6,25\ km.s^{-1}$

Carte mondiale de la profondeur du Moho

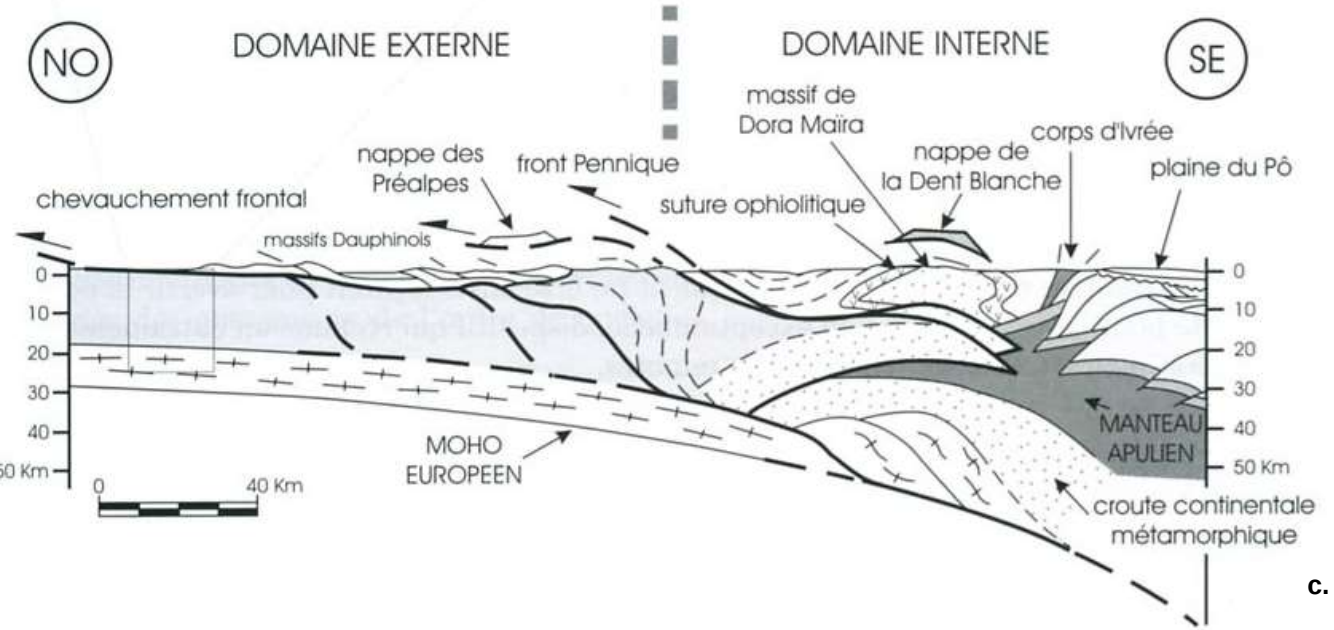




a.



b.



c.

Profil de sismique réflexion profonde à travers les Alpes occidentales
(programme ECORS : étude continentale et océanique par réflexion et réfraction sismiques).

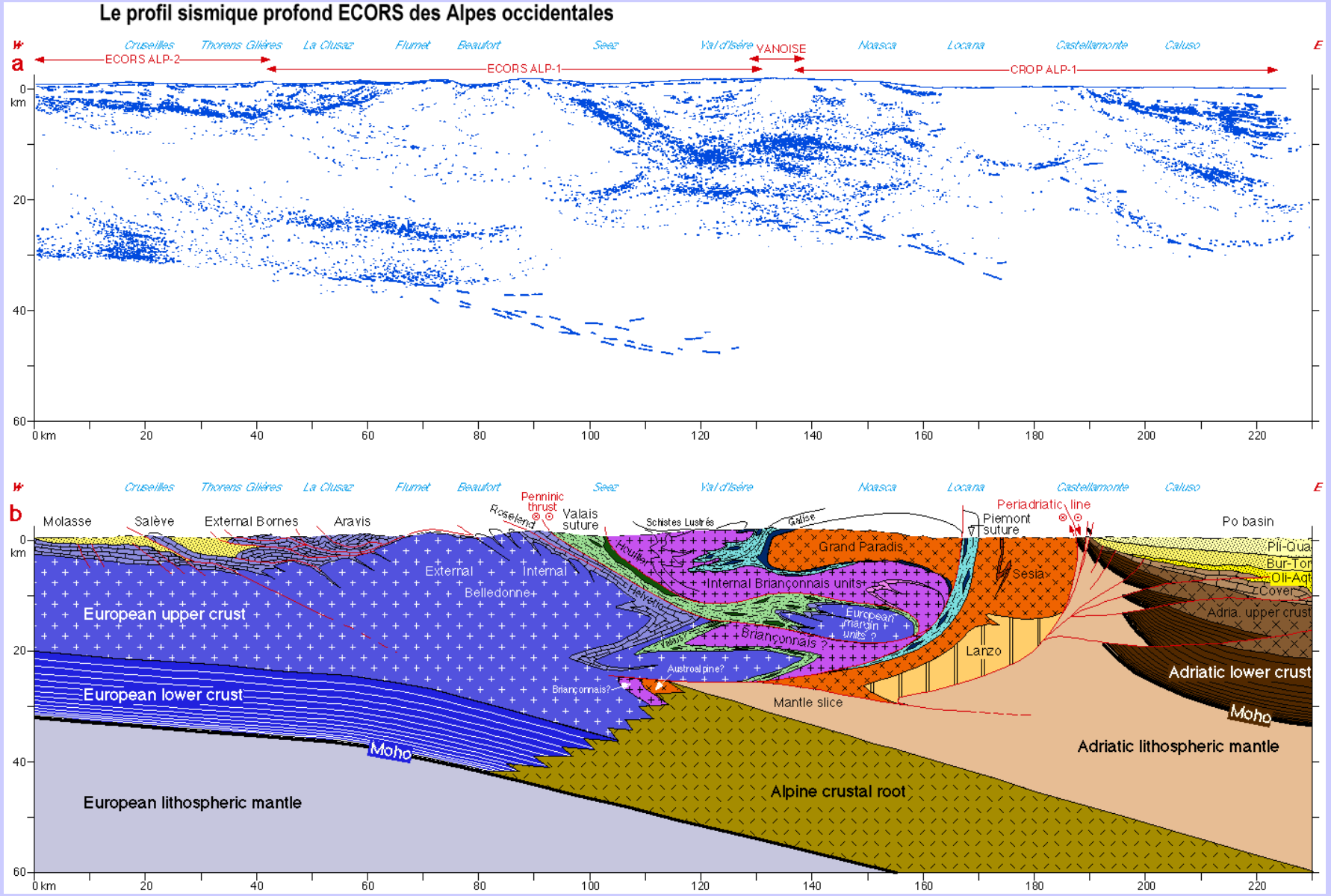
a . Extrait du profil de sismique réflexion au front de la chaîne.

b.Surlignage des principaux réflecteurs.

Dans les deux cas, l'échelle verticale est graduée en
" secondes temps double "
et indique le temps de trajet aller-retour des ondes réfléchies.
La vitesse moyenne de propagation dans la croûte est d'environ 6,25 km.s^{-1}.

c. Interprétation géologique de l'ensemble de la coupe sismique.

(D'après Roure et coll., 1990, in Larroque C. et Virieux J.,
" Physique de la Terre solide ",
G and B Ed.)


Le profil sismique profond ECORS des Alpes occidentales
a
Cruseilles
Thorens Glières
La Clusaz
Flumet
Beaufort
Seez
Val d'Isère
VANOISE
Noasca
Locana
Castellamonte
Caluso
ECORS ALP-2
ECORS ALP-1
CROP ALP-1
km
0 km
20
40
60
80
100
120
140
160
180
200
220
b
Molasse
Salève
External Bornes
Aravis
Roselend
Penninic thrust
Valais suture
Schistes Lustrés
Gallice
Piemont suture
Periadriatic line
Po basin
Grand Paradis
Sesia
Internal Briançonnais units
External
Internal
Belledonne
Houillier
Helvetic
European upper crust
European margin units ?
Briançonnais ?
Austroalpine?
Briançonnais?
Lanzo
Mantle slice
Pli-Qua
Adria. upper crust
Adriatic lower crust
Moho
European lower crust
Moho
Adriatic lithospheric mantle
Alpine crustal root
European lithospheric mantle

PREM (Preliminary Reference Earth Model)

(Dziewonski and Anderson, 1981) velocity structure trough the Earth: ρ = density, α = seismic P-waves velocity, β = S-waves velocities a. a Figure taken from http://shadow.eas.gatech.edu/~anewman/classes/geodynamics/random/prem earth.pdf

TABLE II

Earth model PREM and its functionals evaluated at a reference period of 1 s. Above 220 km the mantle is transversely isotropic; the parameters given are "equivalent" isotropic moduli and velocities. See Table IV for complete elastic constants in this region.

LEVEL	RADIUS KM	DEPTH KM	DENSITY G/CCM	VP KM/S	VS KM/S	QMU	QK	QAL	PHI KM2/S2	KAPPA KBAR	MU KBAR	SIGMA	PRESSURE KBAR	DK/DP	E.P.	GRAVITY CM/S2
1	0.	6371.0	13.08848	11.26220	3.66780	85	1328	431	108.98	14253	1761	0.4407	3638.524	2.3360	0.99	0.
2	100.0	6271.0	13.08630	11.26064	3.66678	85	1328	431	108.88	14248	1759	0.4407	3636.131	2.3363	0.99	36.56
3	200.0	6171.0	13.07977	11.25593	3.66342	85	1328	431	108.80	14231	1755	0.4408	3628.956	2.3365	0.99	73.11
4	300.0	6071.0	13.06888	11.24809	3.65794	85	1328	432	108.68	14203	1749	0.4409	3617.011	2.3369	0.99	109.61
5	400.0	5971.0	13.05364	11.23712	3.65027	85	1328	432	108.51	14164	1739	0.4410	3600.315	2.3375	0.99	146.04
6	500.0	5871.0	13.03404	11.22301	3.64041	85	1328	433	108.29	14114	1727	0.4412	3578.894	2.3382	0.99	182.39
7	600.0	5771.0	13.01009	11.20576	3.62835	85	1328	434	108.02	14053	1713	0.4414	3552.783	2.3391	0.99	218.62
8	700.0	5671.0	12.98178	11.18538	3.61411	85	1328	436	107.70	13981	1696	0.4417	3522.024	2.3402	0.99	254.73
9	800.0	5571.0	12.94912	11.16186	3.59767	85	1328	437	107.33	13898	1676	0.4420	3486.665	2.3414	0.99	290.68
10	900.0	5471.0	12.91211	11.13521	3.57905	85	1328	439	106.91	13805	1654	0.4424	3446.764	2.3428	0.99	326.45
11	1000.0	5371.0	12.87073	11.10542	3.55823	85	1328	440	106.45	13701	1630	0.4428	3402.383	2.3443	0.99	362.03
12	1100.0	5271.0	12.82501	11.07249	3.53522	85	1328	443	105.94	13586	1603	0.4432	3353.596	2.3460	1.00	397.39
13	1200.0	5171.0	12.77493	11.03643	3.51002	85	1328	445	105.38	13462	1574	0.4437	3300.480	2.3480	1.00	432.51
14	1221.5	5149.5	12.76360	11.02827	3.50432	85	1328	445	105.25	13434	1567	0.4438	3288.513	2.3486	1.00	440.02
15	1221.5	5149.5	12.16634	10.35568	0.	0	57822	57822	107.24	13047	0	0.5000	3288.502	3.7545	1.03	440.03
16	1300.0	5071.0	12.12500	10.30971	0.	0	57822	57822	106.29	12888	0	0.5000	3245.423	3.6539	1.02	463.68
17	1400.0	4971.0	12.06924	10.24959	0.	0	57822	57822	105.05	12679	0	0.5000	3187.493	3.5478	1.01	494.13
18	1500.0	4871.0	12.00989	10.18743	0.	0	57822	57822	103.78	12464	0	0.5000	3126.159	3.4649	1.01	524.77
19	1600.0	4771.0	11.94682	10.12291	0.	0	57822	57822	102.47	12242	0	0.5000	3061.461	3.4017	1.00	555.48
20	1700.0	4671.0	11.87990	10.05572	0.	0	57822	57822	101.12	12013	0	0.5000	2993.457	3.3552	1.00	586.14
21	1800.0	4571.0	11.80900	9.98554	0.	0	57822	57822	99.71	11775	0	0.5000	2922.221	3.3230	1.00	616.69
22	1900.0	4471.0	11.73401	9.91206	0.	0	57822	57822	98.25	11529	0	0.5000	2847.839	3.3028	1.00	647.04
23	2000.0	4371.0	11.65478	9.83496	0.	0	57822	57822	96.73	11273	0	0.5000	2770.407	3.2927	1.00	677.15
24	2100.0	4271.0	11.57119	9.75393	0.	0	57822	57822	95.14	11009	0	0.5000	2690.035	3.2911	1.00	706.97
25	2200.0	4171.0	11.48311	9.66865	0.	0	57822	57822	93.48	10735	0	0.5000	2606.838	3.2966	1.00	736.45
26	2300.0	4071.0	11.39042	9.57881	0.	0	57822	57822	91.75	10451	0	0.5000	2520.942	3.3080	1.00	765.56
27	2400.0	3971.0	11.29298	9.48409	0.	0	57822	57822	89.95	10158	0	0.5000	2432.484	3.3242	1.00	794.25
28	2500.0	3871.0	11.19067	9.38418	0.	0	57822	57822	88.06	9855	0	0.5000	2341.603	3.3441	1.00	822.48
29	2600.0	3771.0	11.08335	9.27876	0.	0	57822	57822	86.10	9542	0	0.5000	2248.453	3.3670	1.00	850.23
30	2700.0	3671.0	10.97091	9.16752	0.	0	57822	57822	84.04	9220	0	0.5000	2153.189	3.3919	1.00	877.46
31	2800.0	3571.0	10.85321	9.05015	0.	0	57822	57822	81.91	8889	0	0.5000	2055.978	3.4180	1.00	904.14
32	2900.0	3471.0	10.73012	8.92632	0.	0	57822	57822	79.68	8550	0	0.5000	1956.991	3.4448	1.00	930.23
33	3000.0	3371.0	10.60152	8.79573	0.	0	57822	57822	77.36	8202	0	0.5000	1856.409	3.4714	1.00	955.70
34	3100.0	3271.0	10.46727	8.65805	0.	0	57822	57822	74.96	7846	0	0.5000	1754.418	3.4972	1.00	980.51
35	3200.0	3171.0	10.32726	8.51298	0.	0	57822	57822	72.47	7484	0	0.5000	1651.209	3.5215	1.00	1004.64
36	3300.0	3071.0	10.18134	8.36019	0.	0	57822	57822	69.89	7116	0	0.5000	1546.982	3.5437	0.99	1028.04
37	3400.0	2971.0	10.02940	8.19939	0.	0	57822	57822	67.23	6743	0	0.5000	1441.941	3.5629	0.99	1050.65
38	3480.0	2891.0	9.90349	8.06482	0.	0	57822	57822	65.04	6441	0	0.5000	1357.510	3.5769	0.98	1068.23
39	3480.0	2891.0	5.56645	13.71660	7.26466	312	57822	826	117.78	6556	2938	0.3051	1357.509	1.6435	0.99	1068.23
40	3500.0	2871.0	5.55641	13.71168	7.26486	312	57822	826	117.64	6537	2933	0.3049	1345.619	1.6434	1.00	1065.32
41	3600.0	2771.0	5.50642	13.68753	7.26575	312	57822	823	116.96	6440	2907	0.3038	1287.067	1.6424	1.01	1052.04
42	3630.0	2741.0	5.49145	13.68041	7.26597	312	57822	822	116.76	6412	2899	0.3035	1269.742	1.6420	1.01	1048.44
43	3630.0	2741.0	5.49145	13.68041	7.26597	312	57822	822	116.76	6412	2899	0.3035	1269.741	3.3344	1.01	1048.44
44	3700.0	2671.0	5.45657	13.59597	7.23403	312	57822	819	115.08	6279	2855	0.3026	1229.719	3.2957	1.01	1040.66
45	3800.0	2571.0	5.40681	13.47742	7.18892	312	57822	815	112.73	6095	2794	0.3012	1173.465	3.2443	1.01	1030.95
46	3900.0	2471.0	5.35706	13.36074	7.14423	312	57822	811	110.46	5917	2734	0.2998	1118.207	3.2029	1.00	1022.72
47	4000.0	2371.0	5.30724	13.24532	7.09974	312	57822	807	108.23	5744	2675	0.2984	1063.864	3.1716	1.00	1015.80

https://www.researchgate.net/figure/PREM-Preliminary-Reference-Earth-Model-Dziewonski-and-Anderson-1981-velocity_fig11_1756780

PREM (Preliminary Reference Earth Model)

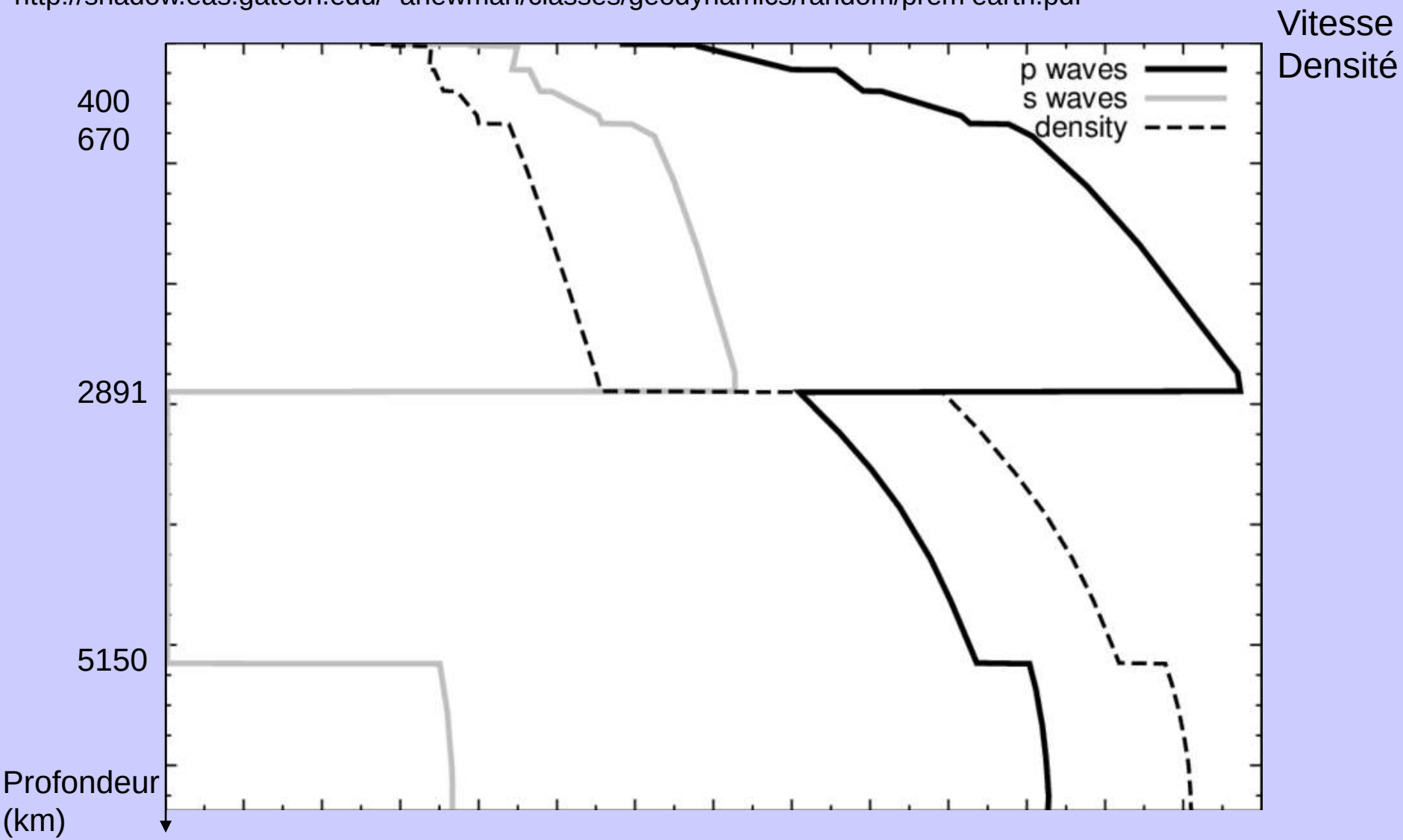
(Dziewonski and Anderson, 1981) velocity structure trough the Earth: ρ = density, α = seismic P-waves velocity, β = S-waves velocities a. a Figure taken from http://shadow.eas.gatech.edu/~anewman/classes/geodynamics/random/prem earth.pdf

LEVEL	RADIUS KM	DEPTH KM	DENSITY G/CCM	VP KM/S	VS KM/S	QMU	QK	QAL	PHI KM2/S2	KAPPA KBAR	MU KBAR	SIGMA	PRESSURE KBAR	DK/DP	E.P.	GRAVITY CM/S2
48	4100.0	2271.0	5.25729	13.13055	7.05525	312	57822	803	106.04	5575	2617	0.2971	1010.363	3.1503	1.00	1010.06
49	4200.0	2171.0	5.20713	13.01579	7.01053	312	57822	799	103.88	5409	2559	0.2957	957.641	3.1393	1.00	1005.35
50	4300.0	2071.0	5.15669	12.90045	6.96538	312	57822	795	101.73	5246	2502	0.2943	905.646	3.1383	1.00	1001.56
51	4400.0	1971.0	5.10590	12.78389	6.91957	312	57822	792	99.59	5085	2445	0.2928	854.332	3.1472	1.00	998.59
52	4500.0	1871.0	5.05469	12.66550	6.87289	312	57822	788	97.43	4925	2388	0.2913	803.660	3.1657	1.00	996.35
53	4600.0	1771.0	5.00299	12.54466	6.82512	312	57822	784	95.26	4766	2331	0.2898	753.598	3.1935	0.99	994.74
54	4700.0	1671.0	4.95073	12.42075	6.77606	312	57822	779	93.06	4607	2273	0.2881	704.119	3.2302	0.99	993.69
55	4800.0	1571.0	4.89783	12.29316	6.72548	312	57822	775	90.81	4448	2215	0.2864	655.202	3.2750	0.99	993.14
56	4900.0	1471.0	4.84422	12.16126	6.67317	312	57822	770	88.52	4288	2157	0.2846	606.830	3.3276	0.99	993.01
57	5000.0	1371.0	4.78983	12.02445	6.61891	312	57822	766	86.17	4128	2098	0.2826	558.991	3.3871	0.99	993.26
58	5100.0	1271.0	4.73460	11.88209	6.56250	312	57822	761	83.76	3966	2039	0.2805	511.676	3.4527	0.99	993.83
59	5200.0	1171.0	4.67844	11.73357	6.50378	312	57822	755	81.28	3803	1979	0.2783	464.882	3.5236	0.99	994.67
60	5300.0	1071.0	4.62129	11.57828	6.44232	312	57822	750	78.72	3638	1918	0.2758	418.606	3.5989	0.99	995.73
61	5400.0	971.0	4.56307	11.41560	6.37813	312	57822	743	76.08	3471	1856	0.2731	372.852	3.6775	0.98	996.98
62	5500.0	871.0	4.50372	11.24490	6.31091	312	57822	737	73.34	3303	1794	0.2701	327.623	3.7582	0.98	998.36
63	5600.0	771.0	4.44317	11.06557	6.24046	312	57822	730	70.52	3133	1730	0.2668	282.928	3.8403	0.97	999.85
64	5600.0	771.0	4.44316	11.06556	6.24046	312	57822	730	70.52	3133	1730	0.2668	282.927	2.9819	0.97	999.85
65	5650.0	721.0	4.41241	10.91005	6.09418	312	57822	744	69.51	3067	1639	0.2732	260.783	3.0086	0.97	1000.63
66	5701.0	670.0	4.38071	10.75131	5.94508	312	57822	759	68.47	2999	1548	0.2798	238.342	3.0358	0.98	1001.43
67	5701.0	670.0	3.99214	10.26622	5.57020	143	57822	362	64.03	2556	1239	0.2914	238.334	2.4000	0.37	1001.43
68	5736.0	635.0	3.98399	10.21203	5.54311	143	57822	362	63.52	2523	1224	0.2911	224.364	2.3868	0.37	1000.88
69	5771.0	600.0	3.97584	10.15782	5.51602	143	57822	362	62.61	2489	1210	0.2909	210.426	2.3734	0.37	1000.38
70	5771.0	600.0	3.97584	10.15782	5.51600	143	57822	362	62.61	2489	1210	0.2909	210.425	8.0910	1.98	1000.38
71	5821.0	550.0	3.91282	9.90185	5.37014	143	57822	363	59.60	2332	1128	0.2917	190.703	7.8833	1.92	999.65
72	5871.0	500.0	3.84980	9.64588	5.22428	143	57822	364	56.65	2181	1051	0.2924	171.311	7.6761	1.86	998.83
73	5921.0	450.0	3.78678	9.38990	5.07842	143	57822	365	53.78	2037	977	0.2933	152.251	7.4695	1.79	997.90
74	5971.0	400.0	3.72378	9.13397	4.93259	143	57822	366	50.99	1899	906	0.2942	133.527	7.2633	1.73	996.86
75	5971.0	400.0	3.54325	8.90522	4.76989	143	57822	372	48.97	1735	806	0.2988	133.520	3.3718	0.83	996.86
76	6016.0	355.0	3.51639	8.81867	4.73840	143	57822	370	47.83	1682	790	0.2971	117.702	3.3369	0.82	995.22
77	6061.0	310.0	3.48951	8.73209	4.70690	143	57822	367	46.71	1630	773	0.2952	102.027	3.3017	0.80	993.61
78	6106.0	265.0	3.46264	8.64552	4.67540	143	57822	365	45.60	1579	757	0.2933	86.497	3.2662	0.79	992.03
79	6151.0	220.0	3.43578	8.55896	4.64391	143	57822	362	44.50	1529	741	0.2914	71.115	3.2305	0.78	990.48
80	6151.0	220.0	3.35950	7.98970	4.41885	80	57822	195	37.80	1270	656	0.2797	71.108	-0.7364	-0.12	990.48
81	6186.0	185.0	3.36330	8.01180	4.43108	80	57822	195	38.01	1278	660	0.2797	59.466	-0.7200	-0.12	989.11
82	6221.0	150.0	3.36710	8.03370	4.44361	80	57822	195	38.21	1287	665	0.2796	47.824	-0.7035	-0.12	987.83
83	6256.0	115.0	3.37091	8.05540	4.45643	80	57822	195	38.41	1295	669	0.2795	36.183	-0.6868	-0.13	986.64
84	6291.0	80.0	3.37471	8.07688	4.46953	80	57822	195	38.60	1303	674	0.2793	24.546	-0.6700	-0.13	985.53
85	6291.0	80.0	3.37471	8.07689	4.46954	600	57822	1447	38.60	1303	674	0.2793	24.539	-0.6700	-0.13	985.53
86	6311.0	60.0	3.37688	8.08907	4.47715	600	57822	1447	38.71	1307	677	0.2792	17.891	-0.6603	-0.13	984.93
87	6331.0	40.0	3.37906	8.10119	4.48486	600	57822	1446	38.81	1311	680	0.2790	11.239	-0.6505	-0.13	984.37
88	6346.6	24.4	3.38076	8.11061	4.49894	600	57822	1446	38.89	1315	682	0.2789	6.043	-0.6428	-0.13	983.94
89	6346.6	24.4	2.90000	6.80000	3.90000	600	57822	1350	25.96	753	441	0.2549	6.040	-0.0000	-0.00	983.94
90	6356.0	15.0	2.90000	6.80000	3.90000	600	57822	1350	25.96	753	441	0.2549	3.370	0.0000	0.00	983.32
91	6356.0	15.0	2.60000	5.80000	3.20000	600	57822	1456	19.99	520	266	0.2812	3.364	0.0000	0.00	983.31
92	6368.0	3.0	2.60000	5.80000	3.20000	600	57822	1456	19.99	520	266	0.2812	0.303	-0.0000	-0.00	982.22
93	6368.0	3.0	1.02000	1.45000	0.	0	57822	57822	2.10	21	0	0.5000	0.299	-0.0000	-0.00	982.22
94	6371.0	0.	1.02000	1.45000	0.	0	57822	57822	2.10	21	0	0.5000	-0.000	0.0000	0.00	981.56

https://www.researchgate.net/figure/PREM-Preliminary-Reference-Earth-Model-Dziewonski-and-Anderson-1981-velocity_fig11_1756780

PREM (Preliminary Reference Earth Model)

(Dziewonski and Anderson, 1981) velocity structure trough the Earth: ρ = density, α = seismic P-waves velocity, β = S-waves velocities a. a Figure taken from http://shadow.eas.gatech.edu/~anewman/classes/geodynamics/random/prem earth.pdf



https://www.researchgate.net/figure/PREM-Preliminary-Reference-Earth-Model-Dziewonski-and-Anderson-1981-velocity_fig11_1756780