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Seismic Velocities and Densities of Rocks

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1. Introduction

Much of our knowledge of crustal and upper mantle structure and composition comes from seismic refraction and reflection investigations. Crustal and upper mantle velocities have been determined on a worldwide basis (e.g., Holbrook *et al.*, 1992; Christensen and Mooney, 1995; Mooney *et al.*, 1998). These studies have often provided earth scientists with information on compressional and shear-wave velocities at various crustal depths, as well as velocity gradients and anisotropies in the form of azimuthal variations and shear-wave splitting from various localities. The velocities are used by seismologists to infer mineralogy, porosity, pore fluid types, temperature, and present or paleolithospheric stress originating from mineral and crack orientations. In addition, seismic reflections originate from contrasts of acoustic impedances, defined as products of velocity and density. To interpret this seismic data requires a detailed knowledge of velocities and densities of rocks, which are provided by laboratory investigations.

This chapter summarizes velocities in many lithologies believed to be important constituents of the lithosphere, experimental aspects of velocity measurements, and velocity–density relationships. The velocities presented in this paper are from a database obtained over a time span of three decades from the rock physics laboratory currently in operation at the University of Wisconsin–Madison. For additional summaries of rock seismic properties, the reader is referred to the articles of Birch (1960), Christensen (1982), Gerbande (1982), Rudnick and Fountain (1995), and Mavko *et al.* (1998).

2. Experimental Technique

Early measurements of elastic wave velocities in rocks were based on the resonant frequencies of vibration of cylindrical bars. These studies were particularly successful in measuring shear velocities (e.g., Birch and Bancroft, 1938). By the early 1950s, advances in electronics made it practical to determine velocities by observing the travel times of pulses in cylindrical rock specimens, usually at the ultrasonic frequency (e.g., Hughes and Jones, 1950). This method of measurement is well suited for studies at high pressures and is presently the standard technique used to obtain both compressional and shear-wave velocities in rocks.

In the pulse transmission technique, transducers are placed on both ends of a rock cylinder usually 2.54 cm in diameter and 4 to 6 cm in length. For velocity measurements as a function of confining pressure, the sample is jacketed with copper foil to prevent high-pressure oil from entering microcracks and pores. Transducers and brass backing pieces are assembled to the ends of the jacketed cylinder, and rubber tubing is slipped over the assembly to exclude the pressure fluid from the transducers and rock specimen. The brass backing pieces, which are attached to the transducers, are ungrounded and the copper jacket surrounding the sample is grounded to the pressure vessel.

The sending transducer converts the input electrical pulse of 50 to 500 V and 0.1 to 10 μsec width, to a mechanical signal, which is transmitted through the rock. The receiving transducer changes the wave back to an electrical pulse, which is amplified and displayed on an oscilloscope screen (Fig. 1). Once the system is calibrated for time delays, the travel time of the elastic wave through the specimen is measured directly on the oscilloscope or with the use of a mercury delay line (Birch, 1960, Christensen, 1985). A major advantage of the delay line is that it increases precision, because the gradual onset of the first arrival from the sample is approximated by the delay line. The rock velocity V_r is given by:

$$V_r = \ell_s V_{\mathrm{hg}} / \ell_{\mathrm{hg}} \tag{1}$$

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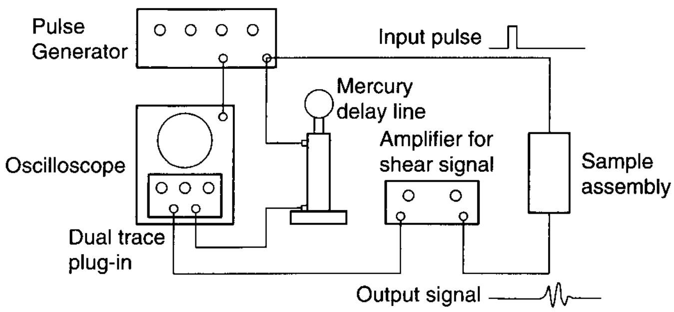

FIGURE 1 Schematic diagram of electronics for velocity measurements.

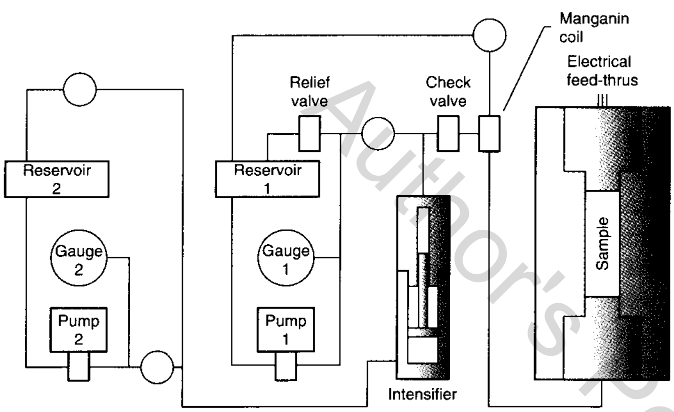

FIGURE 2 Pressure system for velocity measurements to 1000 MPa.

where ℓ_s is the sample length, ℓ_{hg} is the length of the mercury column, and V_{hg} is the velocity of mercury (1.446 km/s at 30°C).

The accuracy of the velocity measurements depends primarily on the signal quality. The transducer response is a function of its natural frequency and damping, which along with propagation through the rock cylinder results in a gradual onset of the first arrival. Signals are much better at high pressures, where cracks in the rocks have been closed, and the transducers are firmly coupled to the rock core face. The accuracy of velocity measurements at pressures above 100 MPa is usually within 0.5% for low-porosity igneous and metamorphic rocks and approximately 1% for most well-indurated sedimentary rocks (Christensen, 1985). The precision of the measurements at elevated pressures is 0.1%.

The pressure system used for the velocity measurements presented in this chapter is illustrated in Figure 2. The interior dimensions of the pressure vessel are 4.5 cm in diameter and 28 cm in length. Two air pumps operate the intensifier, which is capable of generating hydrostatic pressures in excess of 1 GPa. The check valve allows recharging of the high-pressure side of the intensifier. Confining pressure is measured by monitoring the change in resistivity of a manganin coil in contact with the pressure media, a synthetic di-ester base fluid, on the high-pressure side of the intensifier.

3. Rock Velocities

Compressional and shear-wave velocities are summarized as a function of pressure in Tables 1 and 2 for many common rock types. For the igneous and metamorphic lithologies, velocities were measured at intervals of 20 MPa from 0 to 100 MPa and at 100 MPa intervals from 100 MPa to 1000 MPa for both increasing and decreasing pressure. A typical data set from a mafic granulite facies rock is shown in Figure 3. The large rise in velocity below 200 MPa has been shown to be the result of crack closure produced by the hydrostatic pressure (e.g., Birch, 1960). At elevated pressures, the velocity–pressure curves are linear and related to the intrinsic effect of pressure on the mineral components.

Because of their high porosities, sedimentary rocks velocities in Table 2 are reported only to 200 MPa. The porosities of the sedimentary rocks are usually significantly higher than the igneous and metamorphic lithologies. The pores of many sedimentary rocks will not close with the application of pressure (e.g., Hughes and Jones, 1951; Wyllie *et al.*, 1956), and often application of high pressures produces crushing and significant hysteresis between increasing and decreasing velocity measurements.

Several of the igneous and metamorphic rock categories of Table 1 are similar to those summarized by Christensen and Mooney (1995) and Christensen (1996). Notable additions include velocities of rhyolite, obsidian, peridotite, and blueschist, as well as ultra high pressure coesite eclogite from Dabieshan, China. The rhyolite samples are from Bishop, California, and the blueschist samples were collected from western Washington and Alaska.

The sedimentary rocks in Table 2 are all well-consolidated, typical mid-continent platform lithologies. Sandstone and dolostone samples were collected from the UPH 2 and UPH 3 drill

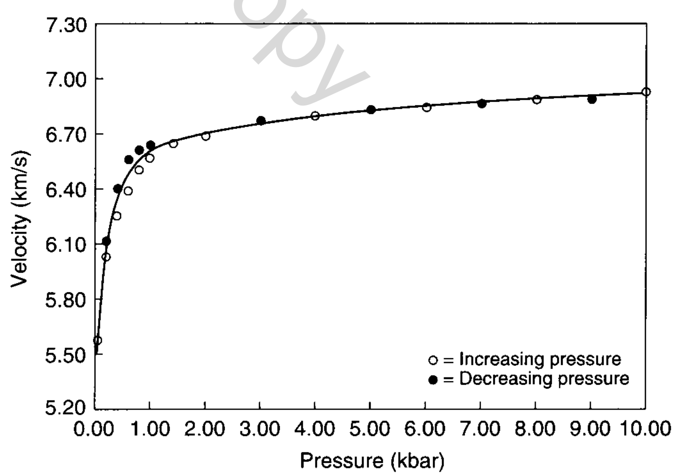

FIGURE 3 Velocity measurements as a function of confining pressure for a mafic granulite.

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TABLE 1 Average Compressional (V_P) and Shear (V_S) Wave Velocities as a Function of Pressure and Densities (ρ) for Igneous and Metamorphic Rock Types*

					200 MPa		400 MPa		600 MPa		800 MPa		1000 MPa	
				ρ	V_P	V_S	V_P	V_S	V_P	V_S	V_P	V_S	V_P	V_S
Igneous rocks														
Plutonic	Granite (GRN)	$S = 108$	Avg.	2652	6.246	3.669	6.296	3.692	6.327	3.706	6.352	3.717	6.372	3.726
		$R = 38$	S.D.	23	0.128	0.116	0.121	0.104	0.121	0.100	0.123	0.096	0.124	0.095
	Diorite (DIO)	$S = 24$	Avg.	2810	6.497	3.693	6.566	3.717	6.611	3.733	6.646	3.745	6.675	3.756
		$R = 8$	S.D.	85	0.161	0.120	0.144	0.110	0.134	0.106	0.120	0.101	0.120	0.099
	Gabbro (GAB)	$S = 174$	Avg.	2968	7.138	3.862	7.200	3.888	7.241	3.905	7.273	3.918	7.299	3.929
		$R = 58$	S.D.	69	0.252	0.129	0.255	0.125	0.258	0.124	0.261	0.124	0.263	0.124
	Diabase (DIA)	$S = 45$	Avg.	2936	6.712	3.729	6.756	3.748	6.782	3.757	6.800	3.762	6.814	3.766
		$R = 15$	S.D.	91	0.266	0.170	0.254	0.156	0.249	0.151	0.244	0.144	0.243	0.141
Volcanic	Rhyolite (RHY)	$S = 9$	Avg.	2050	3.950	2.164	4.162	2.346	4.299	2.462	4.402	2.524	4.479	2.557
		$R = 3$	S.D.	29	0.113	0.180	0.098	0.175	0.095	0.173	0.095	0.171	0.095	0.170
	Andesite (AND)	$S = 30$	Avg.	2627	5.533	3.034	5.712	3.097	5.814	3.130	5.885	3.155	5.940	3.177
		$R = 10$	S.D.	71	0.260	0.208	0.227	0.207	0.224	0.204	0.226	0.207	0.229	0.248
	Basalt (BST)	$S = 252$	Avg.	2882	5.914	3.217	5.992	3.246	6.044	3.264	6.084	3.279	6.118	3.291
		$R = 145$	S.D.	139	0.546	0.302	0.544	0.293	0.543	0.291	0.542	0.288	0.542	0.288
	Obsidian (OBS)	$S = 2$	Avg.	2383	5.810	3.540	5.795	3.515	5.780	3.490	5.766	3.475	5.750	3.456
		$R = 1$	S.D.	13	0.000	0.014	0.007	0.007	0.000	0.014	0.005	0.010	0.010	0.010
Metamorphic rocks														
Low grade	Metagraywacke (MGW)	$S = 27$	Avg.	2682	5.829	3.406	5.950	3.448	6.028	3.474	6.089	3.495	6.139	3.512
		$R = 9$	S.D.	52	0.348	0.291	0.309	0.273	0.283	0.265	0.234	0.253	0.231	0.249
	Slate (SLT)	$S = 27$	Avg.	2807	6.156	3.301	6.240	3.351	6.297	3.384	6.342	3.410	6.379	3.432
		$R = 9$	S.D.	21	0.103	0.106	0.099	0.096	0.094	0.090	0.081	0.081	0.075	0.077
	Phyllite (PHY)	$S = 57$	Avg.	2738	6.243	3.543	6.305	3.569	6.343	3.585	6.373	3.597	6.398	3.608
		$R = 19$	S.D.	46	0.116	0.140	0.093	0.139	0.090	0.140	0.087	0.140	0.086	0.140
	Zeolite facies basalt (ZFB)	$S = 54$	Avg.	2915	6.319	3.413	6.400	3.444	6.454	3.464	6.495	3.480	6.530	3.493
		$R = 18$	S.D.	83	0.270	0.152	0.262	0.152	0.259	0.153	0.256	0.155	0.255	0.156
	Prehnite-pumpellyte facies basalt (PFB)	$S = 36$	Avg.	2835	6.353	3.545	6.436	3.575	6.492	3.595	6.535	3.610	6.571	3.623
		$R = 12$	S.D.	108	0.414	0.237	0.370	0.219	0.354	0.214	0.334	0.207	0.326	0.204
	Greenschist facies basalt (GFB)	$S = 36$	Avg.	2978	6.820	3.883	6.884	3.911	6.925	3.929	6.957	3.943	6.983	3.955
		$R = 12$	S.D.	86	0.227	0.131	0.220	0.134	0.221	0.137	0.223	0.141	0.225	0.143
Medium grade	Granitic gneiss (GGN)	$S = 72$	Avg.	2643	6.010	3.501	6.145	3.553	6.208	3.583	6.245	3.607	6.271	3.627
		$R = 24$	S.D.	46	0.184	0.167	0.135	0.143	0.122	0.137	0.107	0.130	0.101	0.128
	Tonalite gneiss (TGN)	$S = 156$	Avg.	2742	6.180	3.552	6.256	3.585	6.302	3.606	6.337	3.622	6.366	3.636
		$R = 52$	S.D.	68	0.189	0.166	0.171	0.150	0.166	0.148	0.161	0.141	0.160	0.139
	Mica quartz schist (MQS)	$S = 87$	Avg.	2824	6.267	3.526	6.370	3.579	6.433	3.610	6.482	3.634	6.523	3.654
		$R = 29$	S.D.	122	0.307	0.232	0.310	0.227	0.314	0.228	0.321	0.219	0.324	0.217
	Amphibolite (AMP)	$S = 78$	Avg.	2996	6.866	3.909	6.939	3.941	6.983	3.959	7.018	3.974	7.046	3.987
		$R = 26$	S.D.	85	0.224	0.151	0.199	0.136	0.197	0.133	0.197	0.131	0.197	0.130
	Quartzite (QRZ)	$S = 24$	Avg.	2652	5.963	4.035	6.012	4.048	6.045	4.052	6.070	4.053	6.091	4.054
		$R = 8$	S.D.	8	0.074	0.048	0.076	0.042	0.077	0.041	0.078	0.040	0.079	0.040
	Marble (MBL)	$S = 21$	Avg.	2721	6.916	3.653	6.944	3.707	6.961	3.743	6.974	3.770	6.985	3.794
		$R = 7$	S.D.	12	0.085	0.188	0.080	0.181	0.080	0.180	0.080	0.179	0.081	0.179
High grade	Felsic granulite (FGR)	$S = 87$	Avg.	2758	6.411	3.608	6.474	3.631	6.514	3.646	6.545	3.657	6.571	3.667
		$R = 29$	S.D.	79	0.132	0.134	0.127	0.125	0.127	0.125	0.129	0.126	0.131	0.127
	Mafic granulite (MGR)	$S = 102$	Avg.	2971	6.839	3.767	6.902	3.799	6.942	3.820	6.973	3.836	7.000	3.849
		$R = 34$	S.D.	82	0.182	0.121	0.181	0.115	0.184	0.113	0.190	0.111	0.193	0.111
	Mafic garnet granulite (MGG)	$S = 81$	Avg.	3111	7.110	3.974	7.197	4.007	7.249	4.026	7.290	4.040	7.324	4.052
		$R = 27$	S.D.	104	0.184	0.122	0.164	0.108	0.154	0.105	0.154	0.104	0.154	0.104
	Mafic eclogite (MEC)	$S = 51$	Avg.	3485	8.001	4.481	8.078	4.524	8.127	4.553	8.166	4.575	8.198	4.5–94
		$R = 17$	S.D.	67	0.156	0.015	0.160	0.141	0.156	0.143	0.150	0.150	0.149	0.147
	Coesite eclogite (CEC)	$S = 15$	Avg.	3544	8.048	4.567	8.146	4.610	8.187	4.629	8.214	4.642	8.236	4.652
		$R = 5$	S.D.	52	0.169	0.108	0.134	0.100	0.120	0.100	0.113	0.101	0.107	0.102
	Anorthositic granulite (AGR)	$S = 30$	Avg.	2763	6.931	3.736	7.003	3.766	7.049	3.784	7.085	3.798	7.114	3.810
		$R = 10$	S.D.	63	0.134	0.105	0.138	0.105	0.140	0.107	0.145	0.110	0.147	0.112
	Dunite (DUN)	$S = 36$	Avg.	3310	8.299	4.731	8.352	4.759	8.376	4.771	8.390	4.778	8.399	4.783
		$R = 12$	S.D.	14	0.091	0.118	0.083	0.116	0.083	0.116	0.084	0.116	0.085	0.116
	Blueschist (BSC)	$S = 9$	Avg.	3021	7.021	3.876	7.128	3.930	7.188	3.960	7.230	3.981	7.264	3.998
		$R = 3$	S.D.	16	0.040	0.033	0.031	0.032	0.030	0.029	0.031	0.029	0.032	0.030
	Restite (RST)	$S = 9$	Avg.	2874	6.586	3.352	6.757	3.414	6.844	3.441	6.906	3.461	6.954	3.477
		$R = 3$	S.D.	124	0.435	0.638	0.448	0.667	0.457	0.680	0.464	0.690	0.471	0.698

* Densities in kg/m^3 and velocities in km/s; Avg., average; S.D., standard deviation; S, number of specimens (cores); R, number of rocks.

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TABLE 2 Average Compressional (V_P) and Shear (V_S) Wave Velocities as a Function of Pressure and Densities (ρ) for Sedimentary Rock Types*

				ρ	10 MPa V_P	10 MPa V_S	50 MPa V_P	50 MPa V_S	100 MPa V_P	100 MPa V_S	200 MPa V_P	200 MPa V_S
Sedimentary rocks												
Carbonate	Dolostone (DOL)	$S = 49$	Avg.	2661	6.017	3.306	6.264	3.438	6.345	3.486	6.423	3.522
		$R = 28$	S.D.	127	0.382	0.246	0.406	0.242	0.428	0.229	0.430	0.227
	Limestone (LIM)	$S = 31$	Avg.	2659	5.659	3.064	5.891	3.172	5.995	3.200	6.092	3.241
		$R = 29$	S.D.	151	0.665	0.311	0.641	0.274	0.650	0.298	0.654	0.288
Clastic	Sandstone (SSN)	$S = 110$	Avg.	2301	4.551	2.821	4.792	3.003	4.863	3.052	4.948	3.103
		$R = 59$	S.D.	168	0.519	0.313	0.505	0.317	0.506	0.336	0.521	0.344
	Shale (SHL)	$S = 14$	Avg.	2333	3.584	2.273	3.778	2.349	3.918	2.405	3.987	2.474
		$R = 7$	S.D.	68	0.215	0.124	0.208	0.127	0.197	0.128	0.197	0.128
	Siltstone (SLS)	$S = 12$	Avg.	2659	4.621	2.849	5.024	3.020	5.227	3.108	5.430	3.207
		$R = 6$	S.D.	41	0.168	0.077	0.080	0.100	0.067	0.125	0.075	0.140

* Densities in kg/m^3 and velocities in km/s; Avg., average; S.D., standard deviation; S, number of specimens (cores); R, number of rocks.

holes, located in northern Illinois (Coates *et al.*, 1983). Limestone, siltstone, shale, and additional sandstone samples were collected from the Thorn Hill sedimentary section located in Tennessee (Christensen and Szymanski, 1991). Additional shale samples were collected from a quarry in southern Indiana (Johnston and Christensen, 1995).

Compared with velocity measurements as a function of pressure, the determination of velocity temperature derivatives for rocks has not received as much attention by experimentalists. It has been well known since the early studies of Ide (1937) that the application of temperature to a rock at atmospheric pressure results in the formation of cracks, which often produce permanent damage to the rock. Because of this, reliable measurements of the temperature derivatives of velocity require confining pressures high enough to prevent crack formation. In general, pressures of 200 MPa are sufficient for temperature measurements to 300°C.

Several techniques have been used to measure the effects of temperature on rock velocities (e.g., Birch, 1943; Fielitz, 1971; Stewart and Peselnick, 1977; Christensen, 1979; Kern and Richter, 1981; Ramananantoandro and Manghnani, 1978). These studies have used either resonance techniques or more frequently the pulse transmission method. In general, $(\delta V_P/\delta T)_P$ for common rocks ranges from -0.3×10^{-3} to -0.6×10^{-3} km/s/°C, and $(\delta V_S/\delta T)_P$ varies between -0.2×10^{-3} and -0.4×10^{-3} km/s/°C. Temperature derivatives of compressional and shear-wave velocities for some common rocks are given in Tables 3 and 4.

Since increasing temperature decreases velocities and increasing pressure increases velocities, velocity gradients in homogeneous crustal regions depend on the geothermal gradient. The change of velocity with depth is given by

$$dV/dZ = (\delta V/\delta P)_T dP/dZ + (\delta V/\delta T)_P dT/dZ \qquad (2)$$

where V is velocity, Z is depth, T is temperature, and P is pressure. In regions with normal geothermal gradients (25°–40°C/km), dV/dZ is approximately zero (Christensen, 1979).

TABLE 3 Compressional Velocity Temperature Derivatives for Some Common Rocks

Rock	dV_P/dT ($\times 10^{-3}$ km/s/°C)	Reference
Granite, Massachusetts	−0.39	Christensen, 1979
Gabbro, Mid Atlantic Rise	−0.57	"
Basalt, East Pacific Rise	−0.39	"
Anorthosite, Quebec	−0.41	"
Dunite, Washington	−0.56	"
Granulite, New Jersey	−0.49	"
Peridotite, Italy	−0.49	Kern and Richter, 1981
Sillimanite Gneiss, Norway	−0.36	"

TABLE 4 Shear Velocity Temperature Derivatives for Some Common Rocks

Rock	dV_S/dT ($\times 10^{-3}$ km/s/°C)	Reference
Norite, Germany	−0.15	Kern and Richter, 1981
Dunite, Norway	−0.35	"
Peridotite, Italy	−0.39	"
Granite, Germany	−0.21	"
Biotite Gneiss, Norway	−0.17	"
Amphibolite, Norway	−0.21	"

High heat flow regions, however, where geothermal gradients are high, will have crustal velocity reversals as long as compositional changes with depth are minimal.

3.1 Igneous Rocks

Classification schemes for most rock types allow for considerable variations in mineralogy for a given rock type. Because of this, rocks correctly classified as granite, gabbro, and so on show significant variations in velocities and densities; thus, the standard deviations given in Table 1 often reflect this variability.

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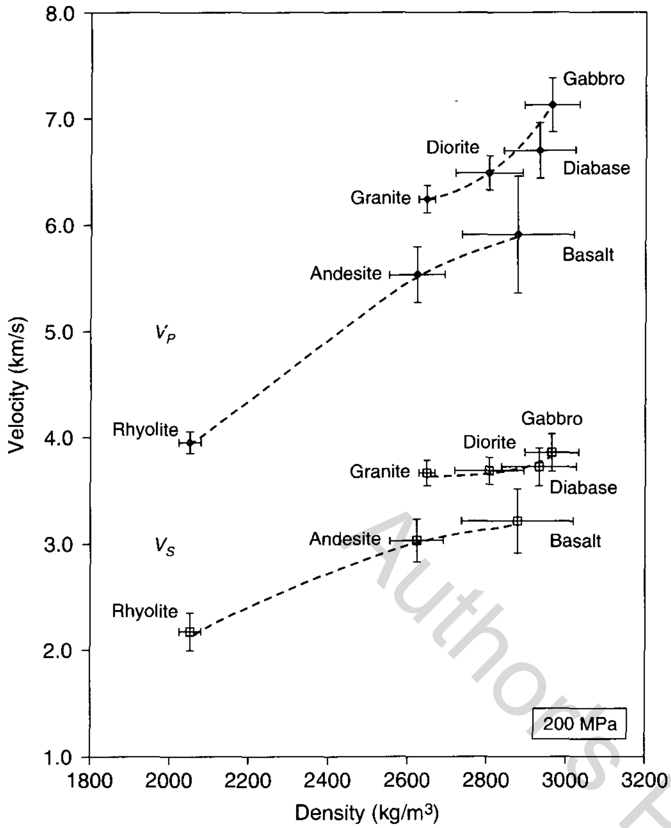

FIGURE 4 Average velocities and standard deviations versus average densities for common igneous rocks.

In addition, the classification of the more common igneous rocks allows for a gradual change in mineralogy as one goes from granite to gabbro, where quartz content decreases, feldspar becomes more calcic, and relatively fast minerals such as amphibole and pyroxene become increasingly abundant. The result is an increase in velocities and densities.

In Figure 4, velocities of the common igneous rocks are plotted against their densities at 200 MPa. For the plutonic rocks, V_P increases gradually from about 6.3 km/s in granite to 6.5 km/s in dorite and 7.2 km/s in gabbro. Shear-wave velocities for these rocks show a less dramatic increase from approximately 3.7 km/s in granite to 3.85 km/s in gabbro. Quartz has a relatively high shear-wave velocity (low Poisson's ratio), thus V_S of granite is almost as high as that of diorite.

The volcanic rocks have lower velocities and densities of chemically equivalent plutonic rocks (Figure 4). Also note the relatively large range in velocities and densities between rhyolite and basalt. These differences are for the most part related to abundant alteration common to the volcanic rocks, which lowers velocities and densities. In addition, stiff vesicles will not close under the range of hydrostatic pressures for which velocities are reported in this chapter and thus contribute significantly to the lowering of velocities and densities.

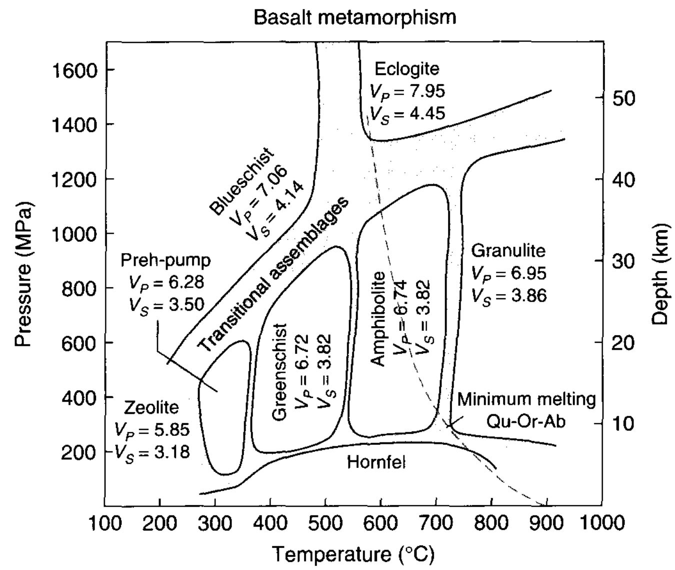

FIGURE 5 Average velocities at temperature and pressure for metamorphosed basalt.

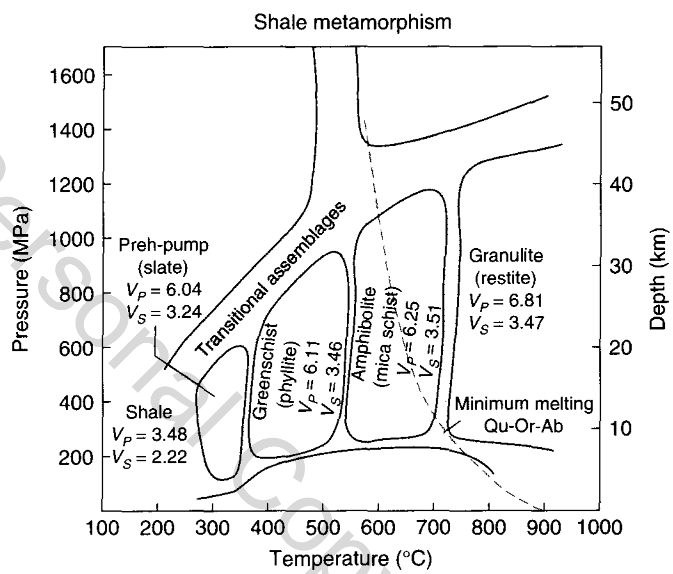

FIGURE 6 Average velocities at temperature and pressure for metamorphosed shale.

3.2 Metamorphic Rocks

For deep crustal studies, velocities in metamorphic lithologies are likely to be of more significance than velocities in igneous rocks. The mineralogies of metamorphic rocks and hence their velocities and densities are functions of many variables, the most important being bulk chemistry, pressure and temperature history, and the availability of water during metamorphism. Earlier studies have shown that velocities generally increase systematically with progressive metamorphism (e.g., Christensen, 1996).

Two important parent rock types for many of the metamorphic rocks of Table 1 are basalt and shale. Figures 5 and 6 show a simplified metamorphic facies classification after Yardley (1989)

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limestone samples occupy the region of high velocity and density, while the sandstone and shale samples are in the low-velocity, low-density region. It should be noted that the shale samples have densities similar to the sandstones, but significantly lower velocities. Also, the siltstone samples have similar densities and shear-wave velocities to the carbonate samples but significantly lower compressional wave velocities. The wide ranges of velocity and density values for the carbonates and the sandstone samples are also illustrated in Figure 7.

The shale samples have significant anisotropy, with the fast direction for compressional waves being parallel to bedding. The fast direction for shear waves is with propagation parallel to bedding and vibration direction also parallel to bedding. Anisotropy in the shale samples can be as high as 30% for both compressional and shear-wave velocity. For further discussion on shale anisotropy, see Johnston and Christensen (1995).

4. Velocity–Density Relationships

The relationship between seismic velocity and density has important implications for multidisciplinary geophysical studies involving seismic and gravity methods. A detailed examination of the density and seismic velocity (at elevated pressures) of rocks of different lithologies can help in the determination of velocity from gravity data or vice versa. This relationship can also be used to determine lithology from either gravity or seismic data. Finally, velocity–density relationships provide information about the acoustic impedances of different rock types, which are important in reflection seismology exploration.

Previous examples of velocity–density relationships include the Nafe-Drake curve (Nafe and Drake, 1957), which is based on experimental velocity data on unconsolidated sediments, sedimentary, metamorphic, and igneous rocks from various sources as well as a theoretical solution for the upper mantle. Birch's (1961) law relates velocity, density, and mean atomic weight for igneous and metamorphic rocks, and Christensen and Salisbury (1975) provide regression line solutions for various oceanic rocks. Gardner *et al.* (1974) define an empirical relationship between velocity and density for a variety of sedimentary rock types. Finally, Christensen and Mooney (1995) present average velocities and average densities for several igneous and metamorphic rocks as well as linear and nonlinear regression line parameters for several depths.

In this chapter we present an empirical relationship between velocity (at elevated pressures) and density for sedimentary, igneous, and metamorphic rocks. Velocity and density data used are averages of 2096 cores from 772 rock samples (Tables 1 and 2). Figure 9 shows a plot of compressional and shear-wave velocity at 200 MPa versus density for the lithologies discussed earlier in this chapter. This figure also includes linear trend lines and their equations for both the compressional and the shear-wave data. The data used for this plot are from Table 1.

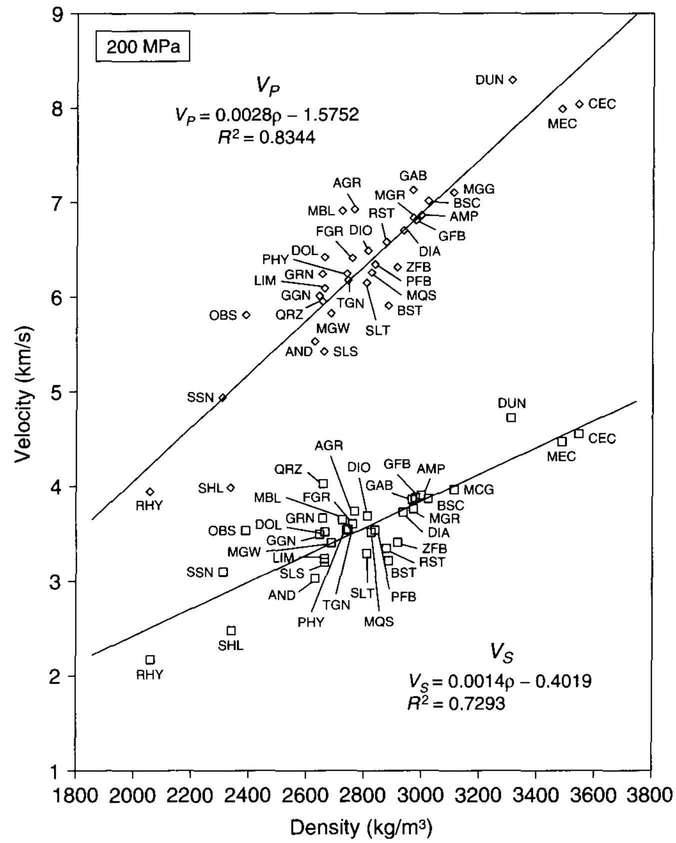

FIGURE 9 Average velocity versus average density for all of the lithologies included in this study.

5. Conclusions

This chapter has been intended to give a summary of laboratory-derived velocities of several different rock lithologies. We have also attempted to correlate important rock properties with velocity, such as density, metamorphic grade, and mineralogy.

All of the velocities and densities reported here were measured in the same rock physics lab currently located at the University of Wisconsin–Madison. We realize that there are many rock types not included in this summary. We feel, however, that those included are a good representation of common lithologies encountered in most crustal and upper mantle geophysical investigations.

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