Investigation of Petrophysical Properties and Ultrasonic P-and S- Wave attenuation in Deccan Flood Basalts, India

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Summary

Petrophysical properties and ultrasonic P-and S- Wave attenuation measurements on 37 Deccan basalt cores recovered from Killari borehole (18°03'07''N, 76°33'20''E), western India, provide a unique and new reference data set for less studied Deccan volcanic province of India. The area is being explored for possible discovery of Mesozoic oil bearing sediments, lying below the thick volcanic cover. Various attempts are being made to improve seismic images below the basalts. Seismic properties are sensitive to various factors such as in-situ conditions, mineralogy, density and porosity, which result in ambiguous interpretation, if not studied properly. Here, we studied petrophysical properties (density, P- and S-wave velocity, porosity) and ultrasonic P- and S-wave attenuation mechanism of the saturated Deccan basalt cores. We found that the rock properties of massive and vesicular Deccan basalt are very different. The Deccan Basalt cores exhibit higher density compared to other flood basalts but surprisingly velocity of the cores is not that high. An interesting relationship between P-wave velocity and porosity has been discussed. The measured values of Q_p range from 33.07-1959.77 and 6.38 - 46.28 for massive and vesicular basalt cores respectively, while Qs ranges from 26.00 - 506.09 and 5.29 - 49.12. It is found that attenuation depends upon porosity and density and the dominant attenuation mechanism is "squirt flow".

Introduction

It is reported that in India, prospective Mesozoic sediments are underlain by multilayered Deccan basalt in western part as well as adjoining continental margin, which needs to be imaged seismically. It is important to mention here that, seismic imaging problems are associated with the physical properties of basalts lying above the sediments, which are related to the episodic lava emplacement processes. In case of Deccan basalts, very limited information is available on physical properties and attenuation of seismic waves. Weiner et al. (1987) calculated Q_p in two tholeiitic basalts from the Deccan Traps, using the torsional pendulum technique. Similarly, Lakshmi et al.,(2014) also presented petrophysical properties of Deccan basalt by analyzing fresh road cutting samples of Deccan traps. Physical properties and attenuation measurements shed light on in-situ basalt properties and help in interpretation of seismic data. However, compressional and shear wave attenuation, in Deccan basalt is not yet investigated systematically in a laboratory. Laboratory investigations of seismic wave attenuation and physical properties of in-situ rocks help determine mechanisms responsible for observed seismic wave energy loss in Deccan basalt. Thus, in this paper, we made an attempt to characterize the physical properties and seismic wave attenuation of Deccan basalt by analyzing 37 saturated Deccan basalt cores, recovered from Killari borehole KLR-1.

Method

To carry out this study, we collected 37 basalt cores from KLR-1 borehole, drilled in Killari, Maharashtra, India. The borehole penetrated 338 m of Deccan flood basalts followed by a further 270 m of 2.57 Ga old Archean crystalline basement. The selected cores represent two important and less studied formations named Ambenali and Poladpur in Deccan volcanic sequence. Care has been taken to pick unweathered, fresh, dry, crack-free, compact and sufficiently isotropic and homogeneous cores. Sample preparation involved polishing the core faces to ensure good coupling between the interfaces and the transducers. The cores were saturated by placing the polished samples in distilled water and subjecting to a vacuum. We preferred saturated cores for preliminary investigations as they better represent the in-situ conditions. The ultrasonic measurements of petrophysical properties and attenuation were carried out at the Rock Mechanics Laboratory of CSIR-National Geophysical Research Institute, Hyderabad, India, following the standard procedures recommended by the International Society for Rock Mechanics (Brown, 1981). The velocity measurements were made on the water saturated basalt cores at room temperature and pressure, following the time-of-flight ultrasonic pulse transmission technique (Rao and Prasanna Lakshmi 2003, Rao et al. 2006) at 1.0 MHz. To facilitate the transmission of sound energy between the transducer and the test sample, the piezoelectric transducers were coupled to the specimen on both sides using machine oil (for P-waves) and honey (for S-waves) as acoustic couplants. The arrival times of P- and S- waves are measured accurately with a precession of ±1% at 1 MHz frequency (Lakshmi et. al, 2013). Attenuation of compressional and shear wave was measured by using 'pulse broadening' method (Ramana and Rao, 1974). The method can be used for determination of Q over a wide range of frequencies. Density (ρ) of the saturated specimen was obtained by using the formula, $\rho = m/v$. For Volume (v) computation, the length and diameter of the specimen

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was measured using a Vernier Caliper with a precision of 0.02 mm. Mass (m) of the core specimen was measured by electronic balance with a precision of 0.001 g.

Physical Properties and Attenuation

Physical properties and attenuation measurements on saturated basalt cores provide a unique reference data set for Deccan flood basalts (Table-1). Measured P-and S-wave velocities, density and porosity is shown in Figure (1). P-and S-wave attenuation with depth is shown in Figure (2).

Table 1: Physical properties (Velocity, Poisson's ratio, Porosity, Young's Modulus and Attenuation) of Deccan basalt cores

	Massive (n=27)		Vesicular (n=10)	
	Average	Range	Average	Range
V_p	5.89±0.36	5.01-6.50	4.15±0.66	3.28-5.48
V_S	3.43±0.18	2.84-3.69	2.45±0.44	1.70-3.24
σ	2.91±0.05	2.80-3.01	2.63±0.16	2.40-2.79
ϕ	1.14±0.84	0.28-3.94	9.92±5.02	1.93-16.59
E	0.24±0.02	0.19-0.27	0.22±0.07	0.09-0.32
Q_P	428.68	33.1-1959.8	20.84	6.38-46.28
Q_S	104.95	26.0-506.1	19.53	5.29-49.12

As shown in Figure (1) the younger Ambenali formation is dominated by massive basalt samples. In this formation, P- and S- velocity varies from 3.66 km/s to 6.49 km/s and 2.47 km/s to 3.69 km/s respectively. 3.66 km/s velocity represents the only vesicular sample from Ambenali formation. The older Poladpur formation is dominated by highly porous vesicular basalt. For this formation, P- and S-velocity range is 3.28 km/s to 6.23 km/s and 1.69 to 3.59 km/s respectively. The Poladpur formation is dominated by highly porous vesicular basalt exhibiting low velocity. P- and S-wave velocity and porosity of massive basalt cores from both the formation are comparable. As expected, seismic attenuation is high in vesicular basalt but surprisingly some of the massive basalt cores also exhibited high attenuation.

The measured values of Q_p range from 33.07-1959.77 and 6.38 - 46.28 for massive and vesicular basalt cores respectively. Measured values of Qs range from 26.00 - 506.09 and 5.29 - 49.12 for massive and vesicular basalt cores respectively. Measured density of Deccan basalts is in the range of 2.8 -3.1 g/cc for massive cores, which is quite high compared to other known basalts. Even highly porous vesicular basalt cores have density values in the range of 2.4-2.7 g/cc. However, P-wave and S-wave velocity is not that high for these cores. Some cores exhibited high density (e.g. 2.87 g/cc) but low velocity (approx. 5.3 km/s).We believe that these anomalous cores underwent hydrothermal alteration and are metasomatized. Hence, these cores are being investigated in details with the help of petrologists and geochemists.

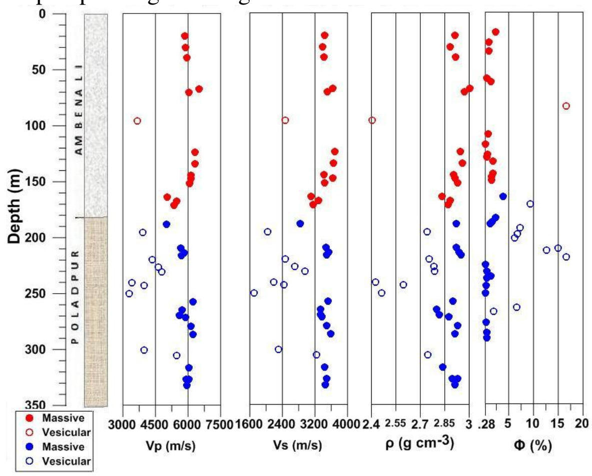

Figure 1: Variation in V_p, V_s, ρ and ϕ with depth for cores

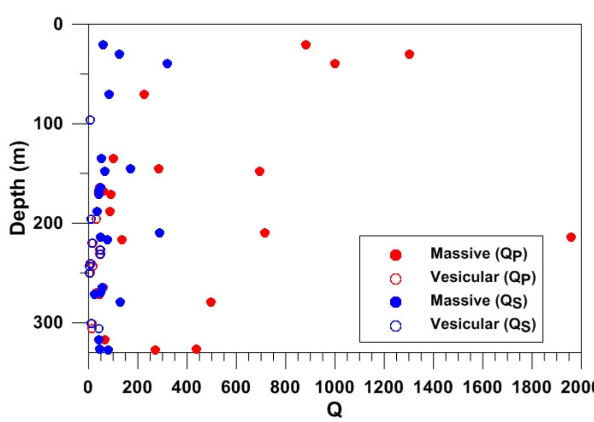

Figure 2: Variation in Q_p, and Q_s with depth for cores

Measured P-wave velocity as a function of porosity is shown in Figure (3). V_p-V_s variation is shown in Figure (4), which is almost linear. We also observed a good correlation between measured density and porosity values. Most of the massive and dense cores exhibit very low porosity (<3%). Compressional wave velocity is also plotted against porosity to look for a possible relationship in Deccan basalt cores (Figure 3). We can see in Figure (3) that an inverse relationship exists between compressional wave velocity and porosity, except for the reported anomalous cores. For preliminary analysis, we assumed that the cores are not subjected to a major change in confining pressure as the

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borehole is very shallow. So we have not yet studied the role of micro-cracks on porosity-velocity relationship, which may be required for non porous massive basalt cores.

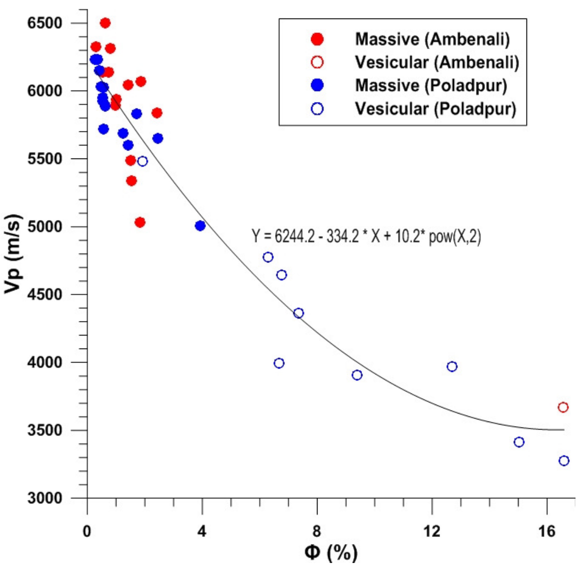

Figure 3: Variation of V_p with Porosity

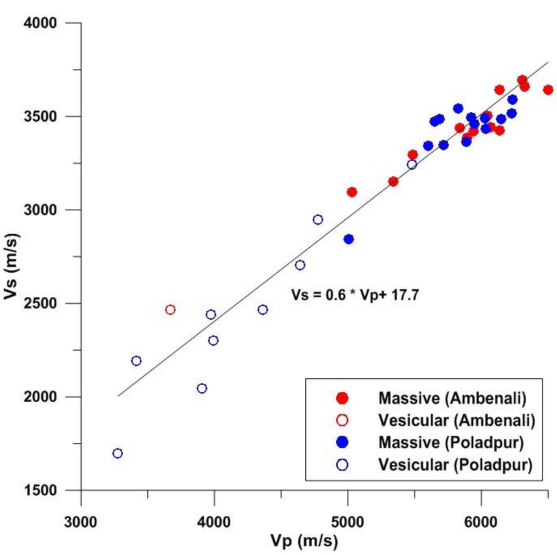

Figure 4: V_p vs. V_s for studied basalt cores

V_p vs. V_s relation is linear for all massive basalt samples but we can see scattering for highly porous vesicular basalt (porosity 9-16%). This could be related to the higher attenuation of shear wave in highly porous samples as compared to compressional wave. Ultrasonic wave attenuation in basalt is dependent on rock physical properties (Wepfer and Christensen, 1991). Therefore, compressional and shear wave attenuation as a function of measured porosity and measured density is shown in Figures (5) and (6) respectively. Lewis and Jung (1989) mentioned that the dependence of compressional and shear wave attenuation on density and porosity, which is observed for ultrasonic frequencies may exist at seismic frequencies also. This would mean that we can roughly estimate expected value of attenuation of compressional and shear wave based on available density and porosity values while carrying out seismic modeling experiments.

Discussions

Values of P-and S-wave velocities and Poisson's ratio are very different for massive and vesicular basalt, which means that in seismic modeling of Deccan basalt, massive basalt layers and vesicular basalt layers should not be clubbed. We have seen that the measured density values are comparatively high for Deccan basalt. This could result in high acoustic impedance. However this does not necessary mean that Deccan basalts have high velocity.

We can see in Figure (5) that seismic wave attenuation increases with increase in porosity. In contrast with the finding of Topkins and Christensen (2001), we observe a nearly linear trend in S-wave attenuation data. A non-linear (parabolic) trend is recognizable in P-wave attenuation data, which becomes more non-linear after porosity attains higher value (12%).

Correlation between attenuation and density (Figure 6) is not as clear as with porosity. We can say that attenuation decreases with increase in density. Basalts cores with density < 2.8 g/cc are highly attenuated and exhibited higher attenuation for shear wave than for the compressional wave. In saturated rocks, many attenuation mechanisms originate from the viscous behavior of pore fluids. To study the effect of pore fluids, we computed Q_s/Q_p and V_p/V_s values for the saturated basalt cores. These values are given in Table (2).

Winkler and Nur (1982) and Murphy (1982) mentioned that for fully saturated samples Q_s/Q_p should be <1, which is observed for our cores, except 5 samples. Two samples (KIL-73 and KIL-64), had some errors and two samples (KIL-78 and KIL-79) whose value is slightly greater than 1 represent very porous vesicular basalt. It is a known fact that attenuation measurement of highly porous vesicular basalt is relatively complicated. Hence, these samples can be re-analyzed. Sample KIL-82 (massive basalt and very good sample) also exhibited anomalous value (Q_s/Q_p = 1.428). It needs further petrological and geochemical investigation. The value of Q_s/Q_p <1 would mean that for fully saturated rock, shear attenuation is more than the

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compressional attenuation because of "squirt flow" mechanism.

Table 1: Measured V_p/V_s and Q_s/Q_p values of 31 satuarted Deccan Basalt cores recovered from KLR-1 borehole

Sample No	Vp/Vs	Qs/Qp
KIL-66 (Massive)	1.6994	0.069
KIL-51 (Massive)	1.7402	0.095
KIL-67 (Massive)	1.7357	0.317
KIL-52 (Massive)	1.7250	0.362
KIL-70 (Massive)	1.7293	0.516
KIL-71 (Massive)	1.7909	0.593
KIL-72 (Massive)	1.6842	0.095
KIL-73 (Massive)	1.6252	1.100
KIL-74 (Massive)	1.6667	0.725
KIL-56 (Massive)	1.6936	0.466
KIL-57 (Massive)	1.7613	0.398
KIL-58 (Massive)	1.6275	0.402
KIL-76 (Massive)	1.6446	0.025
KIL-77 (Massive)	1.6326	0.571
KIL-62 (Massive)	1.7089	0.901
KIL-82 (Massive)	1.6762	1.428
KIL-83 (Massive)	1.7493	0.584
KIL-63 (Massive)	1.7647	0.261
KIL-87 (Massive)	1.7572	0.632
KIL-65 (Massive)	1.7264	0.106
KIL-88 (Massive)	1.6968	0.291
KIL-53 (Vesicular)	1.4878	0.873
KIL-75 (Vesicular)	1.9118	0.382
KIL-59 (Vesicular)	1.7701	0.776
KIL-78 (Vesicular)	1.7168	1.061
KIL-79 (Vesicular)	1.6207	1.096
KIL-60 (Vesicular)	1.5570	0.522
KIL-61 (Vesicular)	1.6280	0.273
KIL-80 (Vesicular)	1.9301	0.841
KIL-86 (Vesicular)	1.7338	0.693
KIL-64 (Vesicular)	1.6910	3.059

Value of Q_s/Q_p can also be used to characterize basalts core's saturation state but for this we need to analyze dry cores too and compare the results. However, a quick glance at V_p/V_s values obtained for saturated cores (with Q_s/Q_p <1) indicate that our results for Deccan basalt are different than the results published by Winkler and Nur (1982) for the saturation state of sandstones. Most of our saturated cores (Q_s/Q_p <1) exhibited V_p/V_s < 1.75 and none exhibited V_p/V_s >2. Thus, a combination of dry and saturated rock analyses would throw light on attenuation mechanism and saturation sate of Deccan basalt.

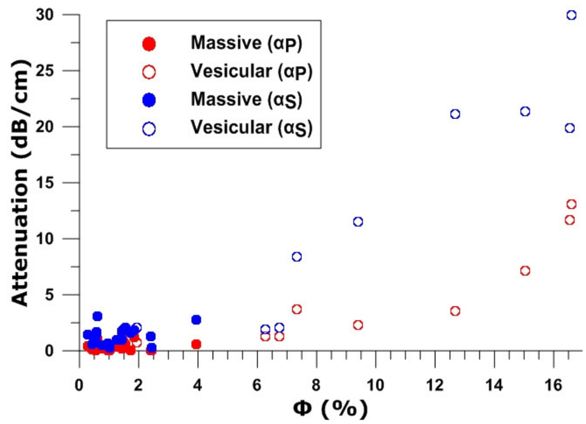

Figure 5: Attenuation as a function of porosity

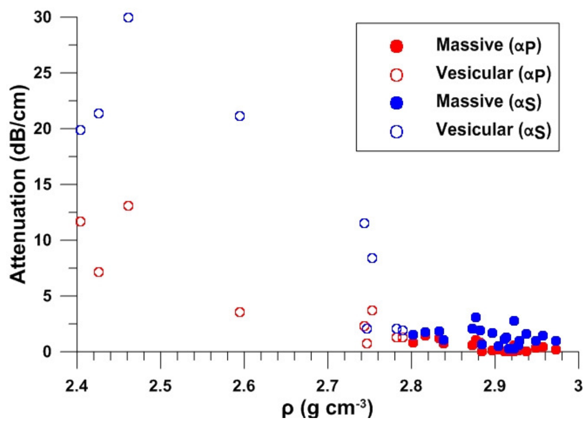

Figure 6: Attenuation as a function of density

Conclusions

In this paper, we present first ever laboratory investigation results of petrophysical properties and ultrasonic P-and S-wave attenuation measurements on saturated Deccan basalt cores, recovered from Killari borehole, India. Preliminary investigations reveal that the Deccan flood basalts appear quite different from similar basalts of many areas.

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Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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