

Significance of Uniaxial and Hydrostatic Pressure Studies on Ancient Oceanic Rocks in Tectonics

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Uniaxial studies are carried out on Indus suture zone rocks of Kashmir Himalaya, which are supposed to be dismembered ophiolites. The percentage difference between the sonic and static determined Young's modulus varies from 4% to 25%. Serpentine showed the lowest value of compressive strength (45 MPa) and pyroxenite gave the highest value (269 MPa), while meta volcanics exhibited narrow limits of 58 to 245 MPa. Standard correlations were obtained for compressive strength to G/P ratio and for compressive strength to tensile strength. Standard correlations for compressive strength to Young's modulus and compressive strength to maximum strain energy will bring out anomalous behavior, if any, of the different rock types, as well as the detection of weak zones. Compressional wave velocity measurements were carried out on all the samples of the sequence up to 10 kbar pressure by simulating the similar hydrostatic pressure conditions of oceanic crust, since the rocks are supposed to represent the ancient oceanic crust (ophiolites). The relationship between the number of cracks/m to compressional wave velocity have been established. These results can be compared with the dredged samples of oceanic crustal rocks of other regions in drilling since these studies are carried out in the same pressure conditions.

Keywords drilling, hydrostatic pressure, ophiolites

Indus suture rock types (for location, see Figure 1) are stated to be dismembered ophiolites (Ramana et al., 1986; Sarma, 1992; Gansser, 1993). Ophiolites form a part of the oceanic crust generated at midocean ridges, from where the crust slowly migrated by ocean floor spreading toward continental margins. Evolution of the Himalayas and the Bengal fan is a consequence of the break up of Gondwanaland. This huge land mass at that time was comprised the present-day continents of Africa, South America, Australia, and Antarctica, and the Indian subcontinent.

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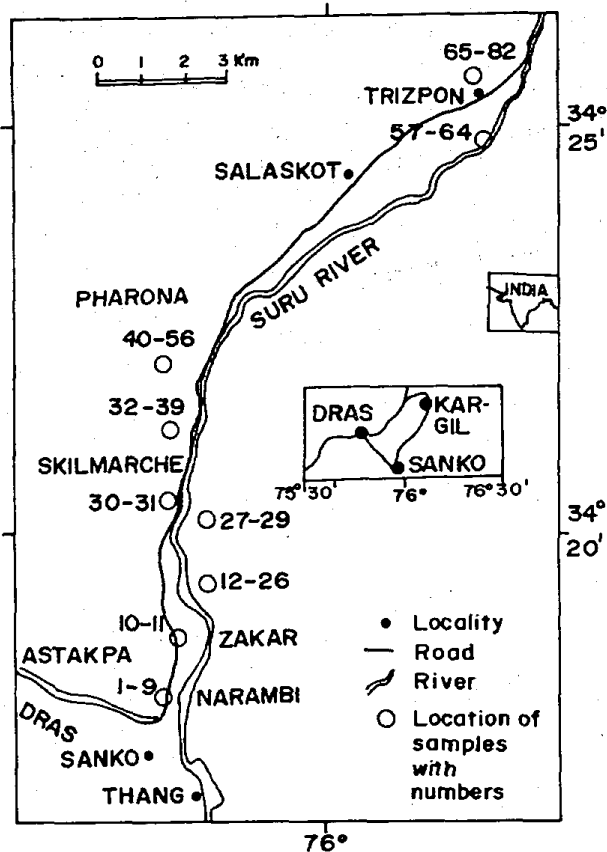


Figure 1. Map showing the investigated area and the location of samples.

The breakup of Gondwanaland occurred across three major and midoceanic spreading centers called the southeast Indian, the southwest Indian, and the central Indian ridges. New oceanic crust was formed across these three spreading centers, and thus the Indian Ocean came into existence. The Indian plate has moved in a northward direction at a faster rate since the Cretaceous period. Around Eocene time (54 million years), the Indian subcontinent or landmass collided with the Asian landmass, thereby closing the Tethys sea (Powell and Gahaghan, 1973; Chaubey et al., 1993; Ramana, 1994; Figure 2). Under these circumstances, slabs of oceanic lithosphere at plate boundaries became detached and now override the continental margins (Coleman, 1977; Ramana et al., 1981) as ophiolites. Considering the importance of the Indus rock types, Young's modulus and Poisson's ratio were determined either by standard static tests or by dynamic methods. Compressive and tensile strengths were determined by uniaxial loading, as they are useful for the determination of maximum strain energy, since this maximum strain energy leads researchers to judge the stability of the rocks. Compressional wave velocities up to 10 kbar pressure were studied by simulating the similar laboratory pressure conditions of the oceanic crust.

Experimental Technique

Uniaxial compression tests are carried out using the geophysical data record's universal testing machine. The test sample is seated in between the two platens of

the deformation controlled testing machine. The test is run until failure. After determining the failure load from the universal testing machine, compressive strength of the rock is evaluated and the tensile strength is evaluated by the Brazilian test. Longitudinal and lateral microstrains at different pressures are measured using a Peekel strain indicator. After determining the longitudinal and lateral microstrains, Young's modulus (E) and Poisson's ratio (σ) are evaluated. After determining the Young's modulus (E) and compressive strength (S_m), the maximum strain energy can be determined. Velocity measurements at different hydrostatic pressures up to 10 kb were carried out using the Birch-Bridgman pressure equipment (Ramana and Gogte, 1979). Without going into further detail regarding the pressure equipment, the Birch-Bridgman equipment is based on the use of fluid compression for attaining hydrostatic pressure.

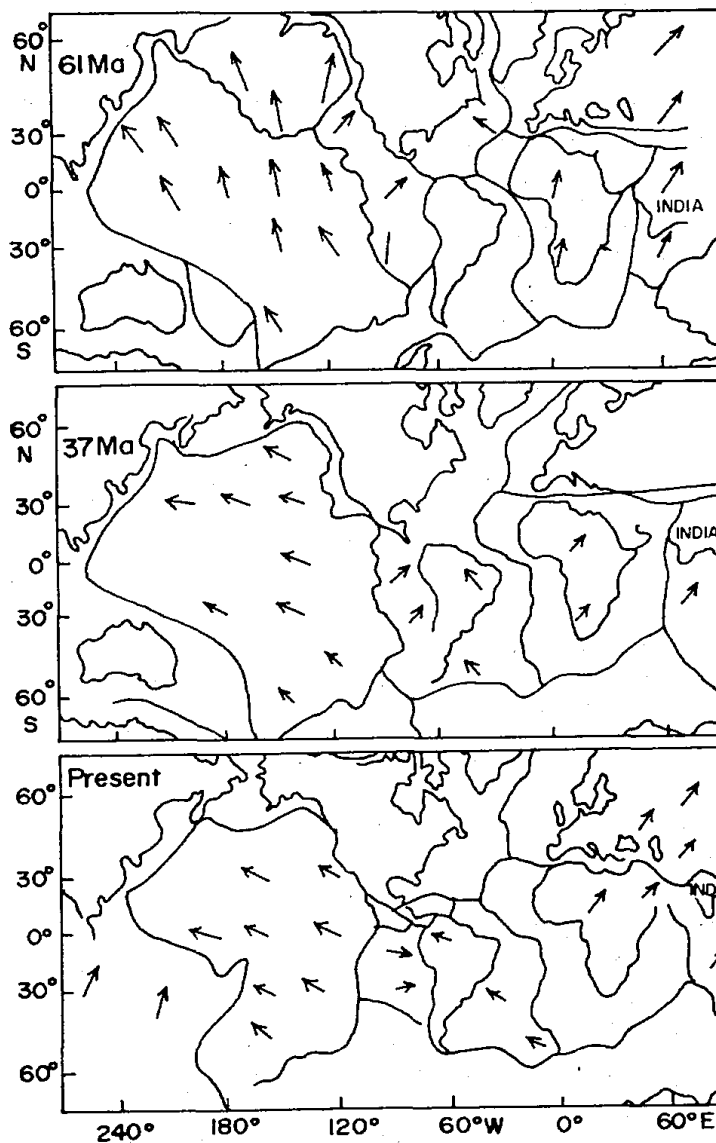


Figure 2. Evolution of plate boundaries over the past 61 Ma. The arrows show the directions and relative rates of motion of the plates.

Results and Discussion

Mechanical properties of Indus suture rocks of Kashmir Himalaya and velocity to fracturization results are in Table 1. An attempt was made to correlate compressive strength to Young's modulus, compressive strength to tensile strength, and compressive strength to maximum strain energy. For volcanics, the effect of groundmass to phenocryst ratio on compressive strength was also attempted.

Young's Modulus

Among the rocks studied in meta volcanics, static Young's modulus indicates a range of 33.3 GPa to 114 GPa, whereas dynamic Young's modulus varies within a range of 80 GPa to 117 GPa. In general, static Young's modulus was lower than dynamic Young's modulus (see Figure 3a).

Poisson's Ratio

The Poisson's ratio evaluated due to static tests varied within narrow limits (0.23 to 0.41) and are slightly higher than the dynamic values.

Compressive and Tensile Strength

The compressive and tensile strengths of the volcanics are 70 to 275 MPa, and 7 to 18 MPa, respectively. The trachytic basalt SK 25B indicated a higher value because of its compact groundmass. In the present study, the least-square solution of the data points for compressive and tensile strengths (including ultramafics) gave the linear regression (see Figure 3b).

$$\text{Tensile strength} = 0.1083 (\text{compressive strength}) - 0.729$$

$$\text{Compressive strength} = 2.8674 (\text{Young's modulus}) - 60.7$$

Compressive strength increases with the tensile strength and also with the Young's modulus.

The interesting results of groundmass/phenocryst ratio (G/P) with compressive strength (S_c) are in Figure 3c, and the least squares, best fit correlation gives the relation

$$\text{Compressive strength} = 5.228(G/P) + 6.59174$$

An increasing trend in the compressive strength (S_c) is observed with the increasing G/P ratio, thereby denoting that an increasing porphyritic nature of the volcanics will cause a decrease in the compressive strength (S_c).

Meta Dolerites

These are quite strong rocks. The compressive and tensile strength of these rocks are in the range 105 to 265 MPa and 5.9 to 17.0 MPa, respectively. The static Young's modulus of sample SK 63B indicated a value of 47 GPa. The maximum strain energy per unit volume ranges from 3.6 to 3.8 kg/cm², supporting the compactness of the grains.

Table 1
Mechanical properties and pressure data of Indus suture rocks of Kashmir Himalaya

Sample No.	Rock type	Compressive strength MPa	Tensile strength MPa	Young's modulus		Maximum strain energy Kg/cm ²	Compressive velocity km/sec	Maximum cracks
				Static Gpa	Dynamic GPa			
SK 2C	Augite Meta basalt	74	18	—	112	0.25	6.35-7.34	3.86-3.65
SK 6B	Meta basalt	139	11	60	—	—	—	—
SK 8B	Serpentinite	100	—	—	69	0.7	—	—
SK 10C	Serpentinite	121	73	—	111	0.6	6.46-7.04	3.78-3.68
SK 47C	Spilitic basalt	—	11	—	122	0.2	—	—
SK 25B	Trachytic basalt	275	8	61	—	—	—	—
SK 44A	Metadolerite	102	11	—	101	0.5	5.69-6.11	3.95-3.86
SK 43A	Spilitic	244	9	—	93	3.2	6.47-6.83	3.78-3.74
SK 20B	Metagreywacke	154	17	60	—	—	—	—
DRN 16A	metabasalt	245	18	—	102	2.9	—	—
DRN 11C	metabasalt	164	9	—	69	1.9	—	—
DRS 17B	Metadolerite	105	21	—	—	—	5.72-6.25	3.94-3.83
KG 2A	Metadolerite	265	17	—	98	3.6	—	—
KG 3B	Metadolerite	265	8	—	92	3.8	—	—
DRN 18A	Pyroxenite	269	5	—	79	4.5	—	—
DRN 18B	Pyroxenite	151	15	—	125	0.9	8.04-8.51	3.52-3.45
DRN 16B	Pyroxenite	219	15	—	123	1.9	6.32-6.66	3.81-3.74
DRM 29A	Pyroxenite	125	10	—	88	0.8	—	—
DRM 5B	Serpentinite	186	14	—	—	—	5.52-5.93	3.98-3.89
DRM 10B	Serpentinite	89	6	—	52	0.8	5.52-5.93	3.98-3.89
DRM 6B	Serpentinite	52	10	—	62	0.2	—	—
DRM 3A	Serpentinite	62	7	—	77	0.3	5.89-6.31	3.90-3.81
DRM 7C	Serpentinite	248	14	—	88	3.5	5.89-6.31	—
DRS 3B	Chert	141	12	—	66	1.5	—	—
SK 88A	Chert	210	10	—	—	—	6.30-6.73	4.0-3.73
KG 1B	Granodiorite	—	—	—	—	—	—	—
DR 26A	Gabbro	—	—	—	—	—	6.37-6.89	3.8-3.70
DRS 2A	Dunite	—	—	—	—	—	5.98-6.26	3.8-3.82
SK 27B	Melange	72	15	33	—	0.8	6.52-7.00	3.7-3.6
DRM 32A	Schist	115	7	—	54	1.2	6.32-6.66	3.81-3.74
DRM 32A	Peridotite	—	—	—	—	—	—	—

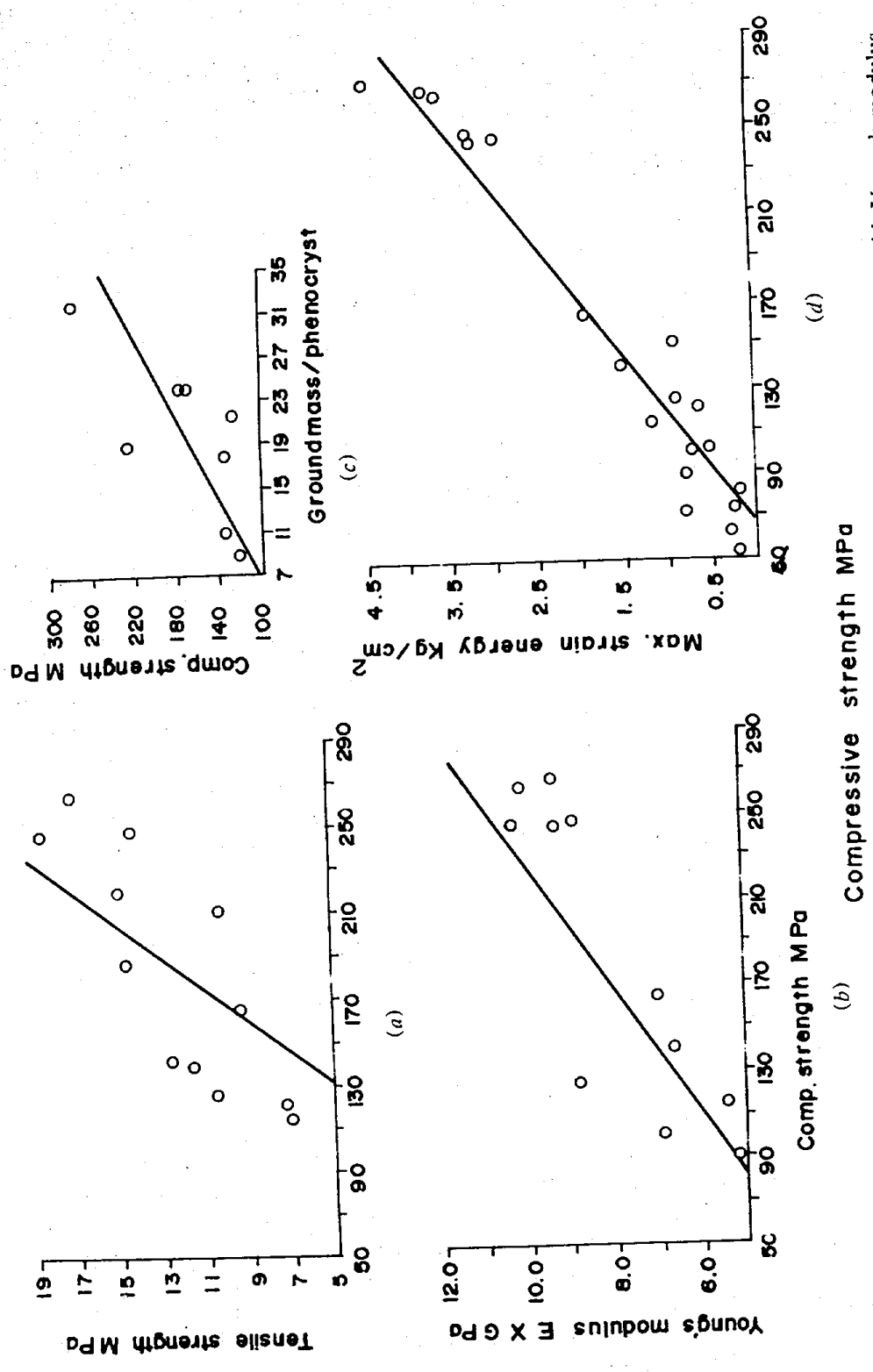


Figure 3. Correlation diagrams of (a) compressive strength to tensile strength, (b) compressive strength with Young's modulus, (c) compressive strength on G/P ratio, and (d) compressive strength with maximum strain energy.

Ultramafics

The static Young's modulus is in the range of 51 to 111 GPa, whereas the dynamic Young's modulus is in the range of 52 to 125 GPa. Due to the denser nature of the rocks, compressive and tensile strengths are indicating high values showing the range of 53 to 269 MPa and 5.9 to 15.9 MPa, respectively.

In the present study, a correlation was also obtained for compressive strength (S_c) and maximum strain energy per unit volume (Figure 3d) for all the rocks of the ophiolitic sequence (including ultramafics). The least-square solution of the data points yielded the following relation:

$$\text{Compressive strength } (S_c) = 51.93 (\text{maximum strain energy}) + 68.3.$$

This suggests that as the compressive strength (S_c) is increasing, maximum strain energy per unit volume is also increasing. This supports the idea that the area is considerably strong, and the rock-occupying zone is stable and strong, i.e., the area occupied by these ophiolitic sequences rocks is considerably strong.

For obtaining the maximum number of cracks through the standard relation that was described later, velocity measurements at different hydrostatic pressures is carried out. Volcanics indicate values between 6.73 and 6.94 km/sec. Meta gabbro indicated an increase in velocity from 6.37 km/sec at ambient pressure to 6.89 km/sec when subjected to pressure of 10 kb. The dunite sample is highly serpentinized; hence, the velocity is 5.98 km/sec at ambient conditions and 6.26 km/sec at 10 kb pressure. In serpentinites an increase in velocity from 6.32 km/sec to 6.66 km/sec is observed when subjected to the same pressure. The Pyroxenite sample indicated a slightly higher value than the other ultramafics (8.04 km/sec at ambient conditions and 8.51 km/sec at 10 kb pressure) and compares favorably with the Newfoundland Ophiolites (Peterson et al., 1974). All the ultramafics fall in the velocity range of layer 3 of the oceanic crustal structure and stand comparable with other ophiolites. Compressional and shear wave velocity trends at depth is given for various ophiolitic sequences in Figure 4. Up to a depth of 5 km, a steep rise in compressional and shear wave velocity trend is observed in all the sequences and then stabilizes in all the areas. This is believed due to the maximum compactness of the pores attained. The compressional wave velocities (V_p) were determined under similar pressure conditions, and an empirical relation is used relating V_p to the number of cracks/m.

This relationship is as follows: $(C^{-2.945}) = V_p/3.5 \times 10^{11}$ where C is the number of cracks/m and V_p is the value of P wave velocity in the rock specimen.

Evaluation of the fracturization (S_p) can be obtained by using the above equation (Sjogren et al., 1979; Dutta, 1984; Subba Raju et al., 1992) and is indicated in Figure 5. As the V_p of rock varieties increased, fracturization decreased, suggesting a more strong and stable representative specimen. This was further verified comparing it with the relation of V_p to maximum strain energy obtained in uniaxial studies. Deviations in the experimental points perhaps reflect the nonuniform nature of the fracturization in the terrain. The results suggest that the area occupied by the specimens having a large number of cracks can be drilled rather easily since the rock-occupied area having a large number of cracks is comparatively weaker than the other region.

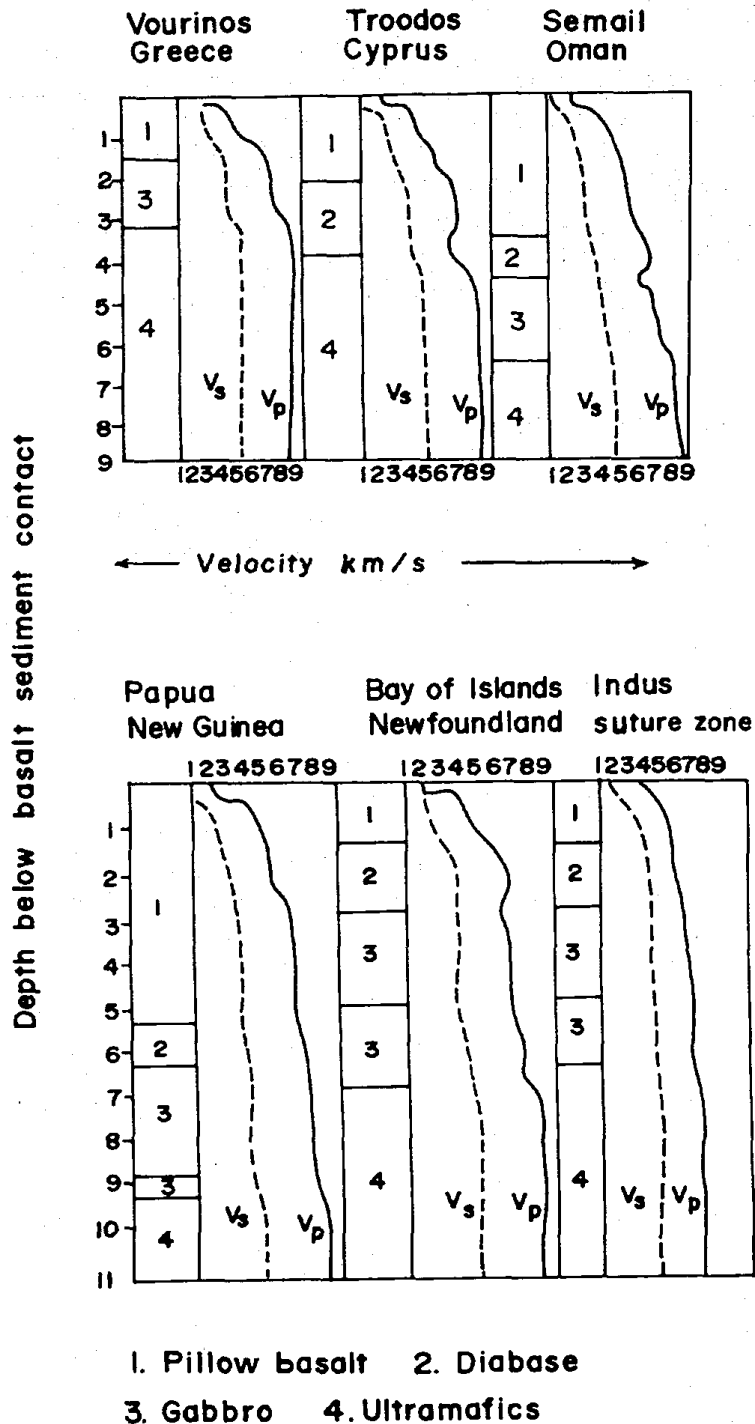


Figure 4. Velocity variation with depth for various ophiolites.

Conclusions

The following conclusions can be reached:

1. The sonically and statically determined values of Young's modulus (E) varied from 4% to 25%, the sonic value being greater in most cases.
2. Serpentinite showed the lowest value of compressive strength $45 \times \text{MPa}$,

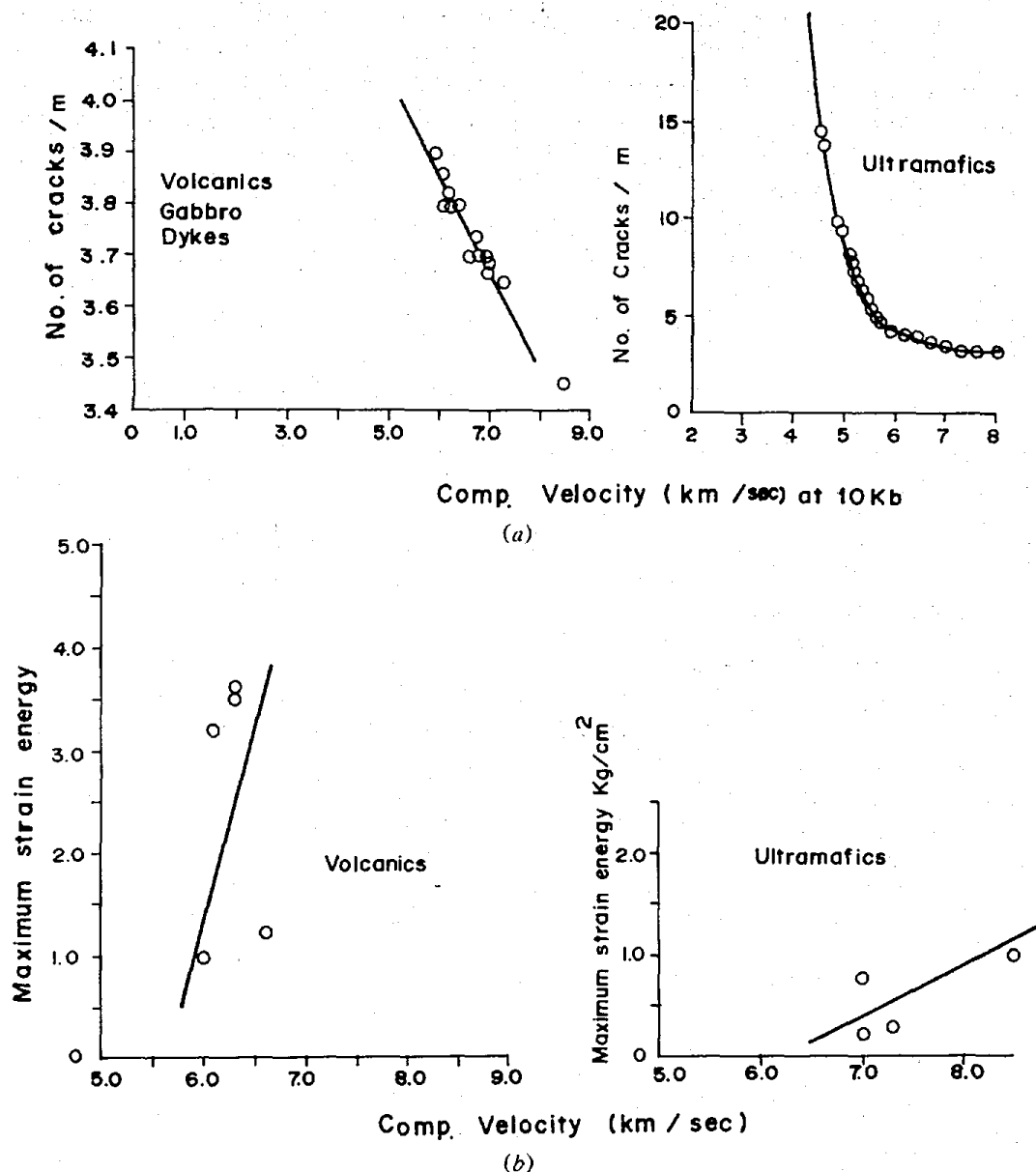


Figure 5. Correlation diagrams of (a) number of cracks/m to P wave velocity at 10 kb pressure, and (b) number of cracks/m to maximum strain energy.

and pyroxenite the highest value 269 MPa, while meta volcanics exhibited the limits of 58.5 to 245 MPa.

3. The derived correlations for compressive strength (S_c) to the parameters like (i) groundmass/phenocryst ratio, (ii) tensile strength (S_t), (iii) Young's modulus (E), and (iv) maximum strain energy bring out the discrepancies and anomalous behavior, if any, of the different rock types in relation to their mechanical properties.

4. The relationship between the number of cracks/m to compressional wave velocity (V_p) and the number of cracks/m to maximum strain energy have helped in the evaluation of the fracturization of the specimens.

5. Systematic study of compressional wave velocity at different hydrostatic pressure will be useful for studying the maximum number of cracks at different pressures; thus, depthwise the increasing clear picture can be understandable in detail.

6. The results can be compared with the dredged samples of the oceanic crustal rocks of other oceans.

7. In general, maximum strain energy of the study area is high, suggesting the more stable nature of the rock terrain under consideration.

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