1. INTRODUCTION

1.1 Velocity Distribution in the Mantle

The study of earth's mantle structure by using travel times or velocity of seismic waves falls in the category of classical methods so far as seismology is concerned. The modern method comprise of analysis of anelasticity, refinements of velocity structure, studies of thermal and magnetic behaviour, among others. Since the interior of the earth is inaccessible, it is only the velocity of P and S waves that provide information about the density and elastic properties of the materials of the earth's interior.

In between 1920-40 many sets of seismological tables were published based on the close studies of some earthquakes. Prominent among them are Gutenberg-Richter (1939) and Jeffreys-Bullen's (1940) travel time tables. These travel times were used to find velocity distribution with depth. On the basis of such velocity distribution Bullen (1967) divided the earth's interior into seven (subsequently eight) layers named as A B C D' D'' E F and G. In accordance with this earth's
model the region between 1000 to 2900 km depth was assigned as 
D' + D'' region and referred to as the lower mantle. The part 
of the mantle between Mohorovicic discontinuity and about 1000 
km depth is called upper mantle. Much work has been done in 
order to understand the nature of the upper mantle. These 
studies (Anderson, 1967) indicate that the upper mantle is 
both radially and laterally heterogeneous.

The lower mantle was previously thought to be homo-
geneous so far as seismic wave propagation is concerned. But 
recent studies (Julien et al. 1973, Sengupta et al. 1978) tend 
to indicate that it is both radially and laterally hetero-
geneous.

The use of underground nuclear explosions in seismolo-
gical studies has ushered in a new era in this field. An under-
ground nuclear explosion is like a controlled earthquake and 
therefore, offers many advantages over a natural earthquake 
(Bullen, 1963). Here origin time and locations are precisely 
known and the travel time data are known with greater accuracy. 
Due to the installation of a large number of seismometers in 
different parts of the world, there has been a vast increase 
in volume of data since the first nuclear explosion, but the 
'resolving power has not been increased' (Bullen, 1963, p-27). 
The data available has mostly been utilized in investigating 
the upper mantle by many workers. Herrin (1968) developed a 
new seismological table using nuclear explosion data along 
with those from earthquakes. Development of very high speed 
computers has added a filip to the analysis of the data,
as in many other fields. In particular the interpretation of surface wave and free oscillation data has been possible with its aid. These studies confirm, compliment and furnish refinements to some of the results obtained by the study of body waves by earlier workers.

Another improvement in the data collection is the establishment of several seismic arrays in different parts of the world. The arrangement gives directly the \( p \left( = \frac{d\gamma}{dA} \right) \) values, required for structural information and as such absolute travel times are not necessary. In the absence of array data \( p \)-values are to be obtained by numerical differentiation of travel time data, which are to be taken from widely spaced stations sometimes. \( p-A \) values are utilized to obtain velocity-depth profile. The interpretation of \( p-A \) curve or the velocity depth profile leads to the understanding of the nature of the earth's interior.

Gutenberg introduced the idea of low velocity layers to interpret amplitude \( -\Delta , \left( \frac{d\Delta}{dT} - \Delta \right) \), and travel time curves (Gutenberg, 1959). He suggested low velocity gradients at epicentral distance ranges 40-44°, 55-60°, 72-75° corresponding to the depths 900-1000, 1400-1500 and 1900-2000 km in the lower mantle. Vvedenskaya and Balakina (1959) noted abrupt changes of the amplitude displacement fields of body waves at 17°, 36-37°, 52° and 70°. Bugayevsky (1960) performing least square analysis of travel time curves found discontinuities at 36-37°, 51-53° and 70-75°. Johnson (1969) using Tonto-Forest array in Central Arizona, obtained a velocity model for the
lower mantle, and found higher velocity gradients near the 
epicentral distances, 34.5°, 40.5°, 49.5°, 59.5°, 70.5° and 
81.5° corresponding to depths, 830, 1000, 1230, 1540, 1910 and 
2370 kms. Gheinry and Tokesz (1967) using LASA array at Montana, 
measured the slope of travel time curve in the range 27-90°.
They found anomalous values at 32.5°, 53° and 73°. Corbithly 
(1970) on the other hand, combining dT/dA from four arrays, 
also found anomalous features at 35-36°, 48-49°, 60°, 68-70° 
and 84-85° indicating anomalous velocity gradients at 850-900, 
1200, 1550, 1800-1900 and 2500 km depths. Wright and Cleary 
(1972), using data of nuclear explosions and earthquakes 
collected by Warramunga Array, constructed a velocity-depth 
profile and found fairly low velocity gradients in between 
the depth ranges, 800-850, 1070-1100, 1260-1330, 1750-1850 and 
2460-2600 kms. Kanamori (1967), Simpson et al. (1971), Green-
field and Sheppard (1969), among others, also found similar 
anomalous velocity distribution in the interior of the earth. 
Garder (1964), taking cue of the breaks in travel time curves 
obtained from nuclear explosions in the central pacific regions, 
constructed a velocity-depth profile in terms of eight layers, 
with velocities increasing in steps. It leads to the interpre-
tation of velocity breaks at epicentral distances near 20°, 23°, 
39°, 52°, 69°, 79.5° and 89.5°. Gopal Krishnan's (1969) study 
suggest lower velocity gradient near 780 km and relatively 
higher velocity gradient near 1200 km.

Since the present study is concerned with the mantle 
between 30° to 90° epicentral distance range, references to
works on the upper mantle have not been given here. However, the studies of some workers on the upper mantle include a part of the lower mantle also. Thus, Repetti (1928) and Dahm (1936) have very early identified a discontinuity at about 950 km, corresponding to nearly 40°. Simpson et al. (1971) suggested small velocity anomalies in the lower mantle. Hoffmann et al. (1961) studying seismograms from large quarry blasts at Utah, U.S.A. found discontinuities at 190, 210, 520, 555 and 910 km depths.

These studies show that though there is agreement on the broad outlines of the structure of the mantle, there is no agreement on the finer details. A concerted and very comprehensive study to describe the nature of the mantle in regard to the transmission of body waves and some associated problems is yet to be undertaken. It seems that there is still scope for investigation of the velocity depth structure to elicit information about the structure of the earth's mantle.

1.2 Attenuation of Seismic Waves

Another field of study for understanding the nature of the interior of the earth is the attenuation of seismic waves. The earth being an agglomeration of different materials of widely varying physical properties under great stress and temperature variation, its behaviour in regard to the transmission of seismic waves is very complicated. The description
of transmission phenomenon of seismic energy consists of determination of velocity of propagation and dissipation. The rate of energy dissipation or anelasticity is, therefore, another important source of information regarding the composition, phase, temperature and other properties of the materials found in the earth's interior. The measurement of the parameter $Q$ or its inverse $1/Q$, called specific attenuation factor has become a central point of research in seismology. It is a dimensionless quantity, and is a measure of loss of energy by absorption, scattering or some other mechanism, indicated by the amplitude variation of the seismic waves. The measurement of $Q$ values of terrestrial materials in the laboratory, and attempts to explain the mechanism of absorption theoretically have been made by many workers. These have been reviewed by Howell (1963), Knopoff (1964) and others (Anderson, 1967).

The measurement of $Q$ of the interior of the earth using seismic waves is beset with many difficulties. Attenuation is associated with related phenomenon like geometrical spreading, scattering, diffraction etc. These factors are not critical in surface wave studies, but pose difficulties in body wave studies. Measurement of $Q$ have been made by Press (1956), Anderson and Fawcett (1964), Sato (1958), Ben-Menahem (1965), Bath (1970) and Lopez-Arroyo (1962), Alsdau et al. (1961), Sarma et al. (1970) and others using body waves, surface waves and free oscillation of the earth. These studies yielded average $Q$ values for the whole earth. Anderson has advanced a method for inverting surface wave attenuation data to get a $Q$-depth profile.
Another approach to derive \( Q \) values by studying spectral ratio of core phases like Sc S, s Scs at near normal incidence is also due to Kovach and Anderson (1964).

Methods of determination of \( Q \), from spectral ratio of the body wave spectra, have been developed by Teng (1968) and Long (1969). The study of \( Q \) by this method made by Long is confined to upper mantle while that of Teng goes up to the core boundary. Asada and Takano (1963) have indirectly determined average \( Q \) value of the earth by analysing the P wave spectra and fitting \( Q \) values. The results seem to vary a good deal both in regards to average \( Q \) value of the mantle or \( Q \)-depth profile. Earlier results indicate increase of \( Q \) with depth. Teng's results, on the other hand, show the increase of \( Q \) up to about 1750 km depth and then a slow decrease up to the core.

A very important factor in the measurement of \( Q \) of the earth is the investigation of frequency dependence of \( Q \). Laboratory measurements of \( Q \) of many different type of terrestrial materials indicate that \( Q \) is independent of frequency for a wide range of frequency, while theoretical investigation implies it to be so up to an empirical cut-off frequency (Futtermann, 1962).

Since the different workers have measured the \( Q \) values of the earth (average or \( Q \)-depth profile) at different frequency ranges, it is difficult to compare their results. The general view is that \( Q \) is low in the upper mantle and high in the lower mantle. But in view of the lateral heterogeneities...
observed down to the lower mantle from travel time studies anomalous-Q regions in the mantle are not ruled out.

In this work the structure of the earth's mantle has been studied by the determination of velocity-depth and Q-depth profiles of the mantle using travel time and amplitude data of refracted P-waves generated by underground nuclear explosions in USSR and USA, and recorded between 30° to 90° epicentral distance range by using simple assumptions. The results obtained by these two methods as well as those obtained by other workers using sophisticated instrumentation and analytical methods are compared.