pesticide microemulsion components and concentrations were obtained. However, whether the selected region is appropriate for practical applications depends on further evaluations such as heat storage stability, cold storage stability and determination of effective content and efficacy. Studies on these aspects are in progress.

Based on the pseudo-ternary phase diagram and orthogonal design, we can intuitively know the relationship between various components in a microemulsion, thus reducing the number of trials. The most potential formula of cyhalothrin microemulsion can be obtained through our approach. Experimental results show that our method is simple and effective and can be of great theoretical significance in the preparation of other pesticide microemulsions.

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Subtrappean Mesozoic sediments in the Narmada basin based on travel time and amplitude modelling – a revisit to old seismic data

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Of late, the search for hydrocarbons amidst Mesozoic sediments hidden below high-velocity Deccan Traps has gained prominence in the quest for delineating new reserves of energy. The presence of Mesozoics is directly evident in the form of a low velocity layer (LVL) prominently indicated on the refraction records. To delineate such sediments, seismic refraction/wide angle reflection studies were carried out in different parts of India. Seismic data from the Deep Seismic Sound profile in the western part of the Narmada–Son lineament (NSL) that passes through the Narmada and Tapti rivers is used for this study. Since imaging of LVL is not possible from the refraction data alone, we have used travel time skips on the refraction records along with reflections from the top and bottom of the LVL. Data from reciprocal shot points are used for confirmation and precise delineation. The analysis of seismic refraction and wide angle reflection data shows a possible existence of low-velocity Mesozoic sediments of considerable thickness sandwiched between the high velocity thick Deccan Traps and the basement.

Keywords: Deccan traps, low velocity layer, Mesozoics, Narmada–Son lineament.

DEEP seismic sounding (DSS) studies have been undertaken by National Geophysical Research Institute (NGRI) in different geological/tectonic provinces of India to explain the tectonics and unravel the evolutionary processes of various regions such as the Himalayas, Delhi–Aravalli fold belt, Central India, Cuddapah basin, Mahanadi basin, Bengal basin, Koyna region, Saurashtra and Kutch, Dharwar craton and the Southern granulite terrain, etc. All these investigations were remarkably successful and provided the key inputs for understanding the geodynamics of respective regions. The near surface geological patterns are manifestations of deep-seated structural variations and thus the shallow structure is in general, controlled by the deep crustal structure. The irregularities and the distribution of the structural patterns like faults and fractures are associated with mineral deposits[1]. The low velocity layers overlain by hard

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terrains are the probable locations for accumulations of hydrocarbons. This has inspired us to re-look into the old DSS data collected by NGRI along the N–S trending Thuadara–Sendhwa–Sindad DSS profile (Figure 1) in the western part of the Narmada–Son lineament (NSL) in Central India. Since the Mesozoic sediments (Bagh and Lameta beds) are exposed to the north of the profile, it is anticipated to exist below the Deccan Trap covered area.

The earlier interpretation of the data[2] was mostly confined to the crustal structure. The ray tracing technique to delineate the basement configuration was performed only from a few shot points with large data spacing. The data was originally recorded in the analog form and subsequently digitized. The trace normalized record sections were produced. The analysis and reinterpretation of the digitized data[3] revealed a thick layer (1000–2800 m) of Mesozoic sediment below the Deccan trap cover. However, this study employed the travel time modelling techniques and no corroboratory modelling using the amplitudes was taken up. A study using the near vertical reflections[1] brought out the low velocity layer in the upper crustal structure which was also confirmed using the first arrival refraction data based on 'skip' phenomena. Dynamic and kinematic modelling of the seismic data[4] has brought out the high velocity layer at the midcrustal depth above the Moho. A five-layer velocity model derived therein also does not speak much about the shallow structure extending up to the basement.

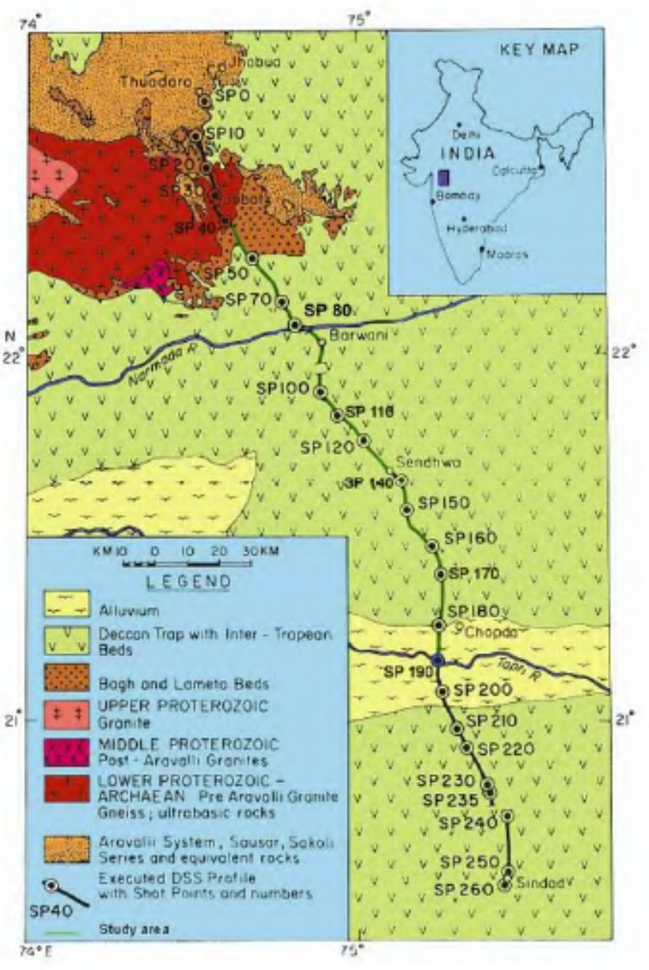

Figure 1. Location of the Thuadara–Sendhwa–Sindad seismic profile over the geological map along with shot points (SP). Legends show various geological units in the study area. Inset shows the study area on the Indian map.

It is felt that the availability of latest software/packages (Rayamp) combined with the digitized data could be used to further refine the basin structure and redefine the extent of the hidden sediments. In the present study, we use the synthetic seismograms and the reflections from the top and bottom of the low velocity Mesozoic sediments for confirming the earlier findings.

The trace normalized record sections pertaining to six shot points were selected among the 25 shot points with the objectives of mapping the Mesozoic sediments sandwiched between the Deccan Trap and underlying granitic basement. Shot points 40, 80, 110, 140, 170 and 190, which cover most part of the Deccan-covered area, were utilized for the delineation of the sediments and the vertical extent of Deccan traps.

We have computed the synthetic seismograms using the model that was derived to match the first arrival refraction data. The reflections from the top and bottom of the low velocity layer are generated along with the synthetic seismograms. Adjustments in velocity and depth parameters were made until a satisfactory match could be achieved between the observed and computed travel times and synthetic seismograms. The modelling of the strong band of reflections from the bottom of the LVL from most of the selected shot points has yielded the anticipated results.

The NSL is a unique feature extending about 1500 km from the west coast of India to Jabalpur in Central India and beyond Shillong plateau in the east. The important feature is the Satpura range, regarded as a horst delimited by Narmada and Tapti faults in the north and south respectively. The Narmada basin is one of the marginal rift basins in the west along with the Kutch and Cambay basins. It has originated during Mesozoic time and received varying thickness of sediments[5]. These sediments were uplifted, faulted and covered by traps during the Late Cretaceous times. Some researchers[6–8] believe that the Narmada and Tapti lineaments together represent an intraplate rift with a central (Satpura mountains) horst bounded on each side by grabens: the Narmada graben on the north and the Tapti graben on the south. Marine Cretaceous sediments (Bagh beds) occur in the lower (western) part of the Narmada valley and their extension is unknown, as they are covered by the Deccan Traps. The Bagh fauna has close similarities with that of the Cretaceous fauna of western India. Therefore, it is assumed that the sedimentation took place during the Cretaceous time.

The 260 km long DSS profile situated in the western part of the Indian shield runs across the western part of the NSL (Figure 1). The seismic data were collected along the profile using 60 channel Russian POISK equipment with the geophone interval of 200 m. 25 shot points were selected at an interval of ~10 km for recording up to a distance of at least 40 km so that the data can delineate the shallow structure. This profile covers the exposed Deccan Traps almost all along its course and crosses a patch of Mesozoic Bagh and Lameta beds in the North. The other geological formations include the Proterozoic Aravallis and equivalent rocks and the Archean granitic gneisses in the northern part. The profile crosses the Narmada and Tapti rivers near SP 80 and SP 190 respectively. A small patch of alluvial deposit is exposed in the southern part of the profile. The elevation of the region varies between 150 and 400 m above the mean sea level.

In the crustal seismic studies, the refraction and wide angle reflection data are used to determine the velocity structure of a region, owing to the tacit assumption that the subsurface structure has continuous increase of velocity with depth. However, in case of velocity inversion, viz. LVL underlying a high velocity layer, the first arrival refraction data does not normally possess information on the velocity and thickness of the LVL. Under some favourable conditions, where the high velocity layer is thinner than the underlying LVL, a shadow zone (skip/shift) may be observed in the first arrivals. This is due to the fact that refraction takes place from the top of the high velocity layer above and below the LVL, thus exhibiting a shadow zone/skip. The magnitude of skip is a function of the velocities and relative thicknesses of high and low velocity layers, other parameters remaining constant. Such a skip in travel time, if observed from several shots, suggests a velocity inversion in the subsurface structure. Delineation of such subsurface structures could be achieved through 2-D forward modelling technique[9] involving first arrival travel time data and using the skips (Table 1). In addition to the first arrival refraction data, the sub critical and wide angle reflection data from top and bottom of the hidden sedimentary layers provide constraints on delineating the LVL.

The Deccan Traps cover a significant part of Indian landmass, extending over more than 500,000 sq. km. Though it is difficult to recognize the LVL under high velocity layers in the refraction data, the analysis of travel time shifts in the first arrivals makes it possible to identify the LVL[10–12].

With the help of model studies[13], besides the attenuation effects, the velocity gradient of the high velocity cap layer is a critical parameter in determining the termination point of the diving wave through the cap layer and thus the skip in first arrivals. It is shown that while the time shift is directly proportional to both, the thickness of the LVL and the gradient of the overlying layer, particularly when it is small; the velocity gradient greatly affects the magnitude of time shift. However, for greater values of gradient, the time shift reaches near saturation.

In view of the above uncertainty, it is advisable to use both travel times and amplitudes of coherent phases reflected from the top and bottom of the low velocity layer for better control on its thickness. It is always not possible to observe the reflection amplitudes at pre-or near-critical ranges. In such cases, the analysis of travel time shifts in the refraction data does provide a reasonably accurate estimate of the thickness of the LVL.

2D forward ray tracing technique[9] is an effective algorithm for computing synthetic seismograms in laterally inhomogeneous media. The method is based on zero-order asymptotic ray theory (ART), which has high frequency approximation, corresponding to the geometri-

Table 1. Skips observed in the first arrivals vis-a-vis derived configura tion of LVL

SP no.	Magnitude of skip (in red. travel time in s)	Approximate thickness of LVL (in m)
SP 110	0.22	1700
SP 140	0.27	2000
SP 170	0.31	2300

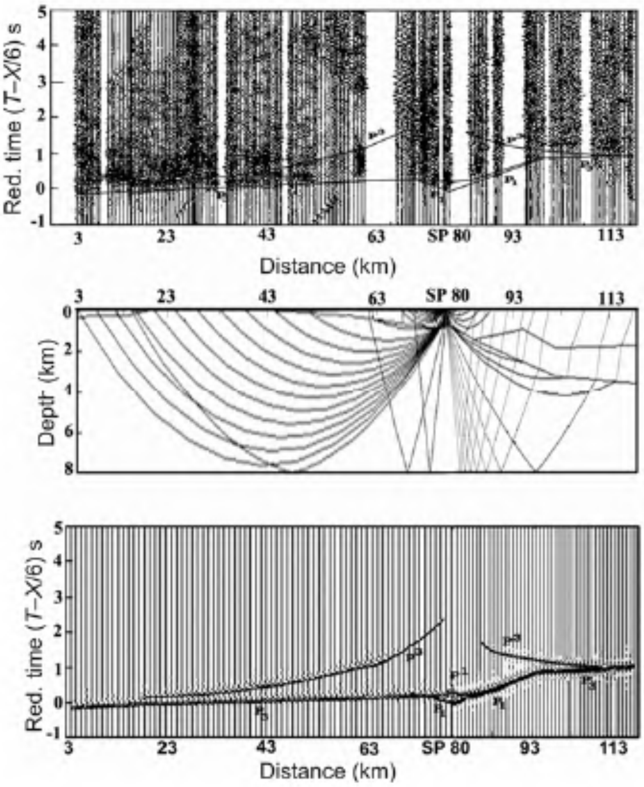

Figure 2. Observed and synthetic record sections of SP 80, where P_1 and P_3 are refraction phases from the trap and basement layers. P^1 and P^3 denote the reflection phases from the bottom of trap (4.85 km/s) and bottom of basement (6.0 km/s) respectively.

cal optics solution. It is primarily intended for use in refraction and reflection studies. A 2-D velocity model is divided into a number of boundaries and each with a velocity and gradient assigned to it. Each boundary contains constant seismic parameters. Amplitudes are determined by generating spreading of spherical wave fronts and energy partitioning at interfaces. The study area is considered very important on the basis of probable existence of the Mesozoic sediments hidden below the Deccan Traps. The amplitude character from the top and bottom of the LVL is an indication of thickness of the LVL overlying the basement. In some of the sedimentary basins in India (Saurashtra[14] and Kutch[15] basin) refraction data have shown the LVL that is sandwiched between the high velocity layers. The time shift in the travel time plots may also be an indication of low velocity layer in the sedimentary layers. It depends upon the thickness of the trap layer. If the velocity varies between two layers before and after the time shift it is evident that there is a possibility of the presence of LVL in the sedimentary layers.

To unravel this and to reconfirm earlier findings, the composite trace normalized record sections were plotted. By looking at the seismograms, 'skips' in first arrivals and strong band of later arrivals (reflections) were noticed for about 6 out of 10 shot points that were digitized. The reflections were initially picked from the records of one shot point and a model was prepared using the Rayamp program. On getting the satisfactory result, the attempt has been extended to the rest of the data sets and finally we derive a velocity with an LVL that produces strong reflections from the top and bottom of the LVL, comparable to the observed data.

The exposed Deccan Trap shows a minimum thickness near SP 40, and continues deepening up to a maximum of ~2500 m. Barwani–Sukta fault crosses at SP 80 near Narmada river and is well observed in the record section. The models using ray tracing technique for SP 80, SP 140 and SP 170 are presented in Figures 2–4. It may be noticed that the basinal part starts nearly below SP 80 and modelling results show a simple two layered structure extending down to the basement. The basement velocity is found to be about 6.1 km s^{-1} which is covered by a sedimentary formation having a seismic velocity of 4.85–5.0 km s^{-1}. SP 110, SP 140 and SP 170 were located in the basinal part of the Narmada–Tapti graben. The modelling results for SP 140 and SP 170 are shown in Figures 3 and 4 respectively. SP 140 lies right over the centre of the basinal structure. To the south of this location, the

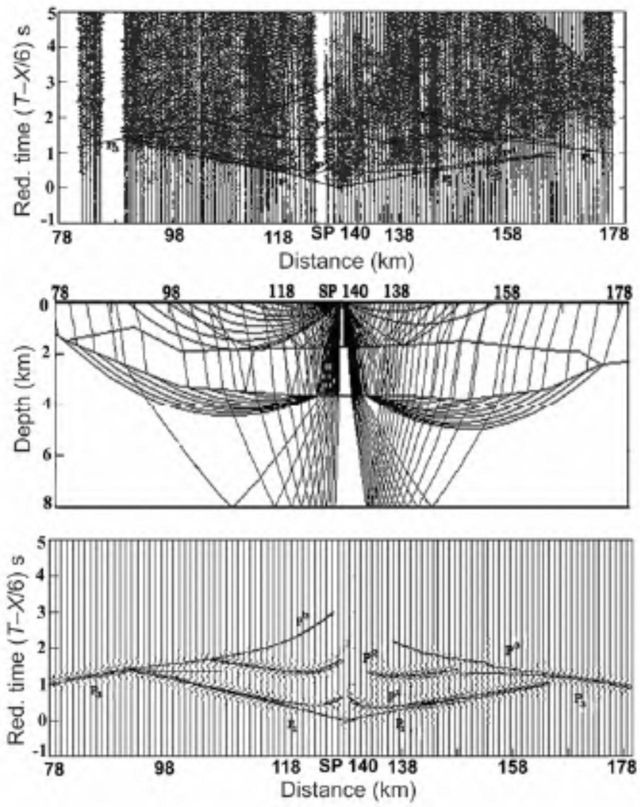

Figure 3. Observed and synthetic record sections of SP 140, where P_1 and P_3 are refraction phases from the trap and basement layers. P^1, P^2 and P^3 are the reflection phases from the bottom of trap (5.00 km/s), bottom of LVL (3.2 km/s) and bottom of basement (6.0 km/s) respectively.

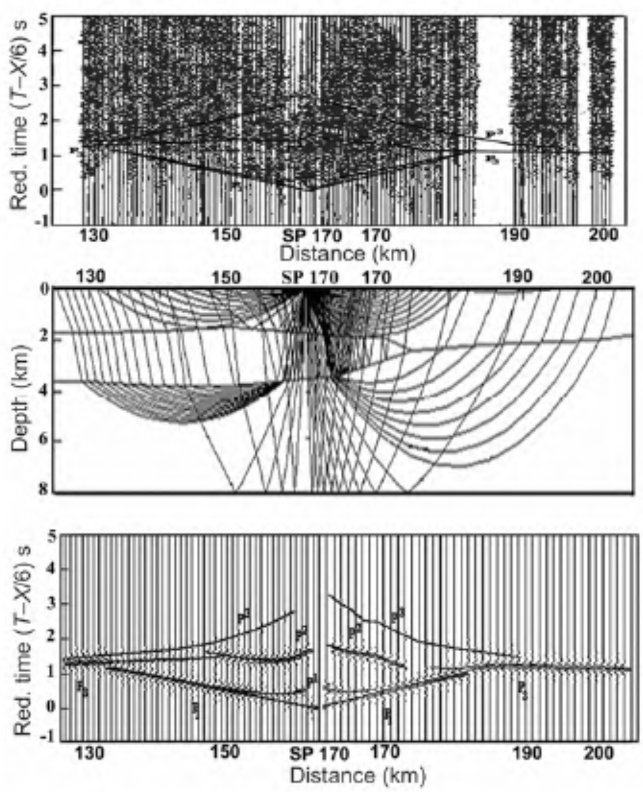

Figure 4. Observed and synthetic record sections of SP 170, where P_1 and P_3 are refraction phases from the trap and basement layers. P^1, P^2 and P^3 denote the reflection phases from the bottom of trap (4.95 km/s), bottom of LVL (3.2 km/s) and bottom of basement (6.0 km/s) respectively.

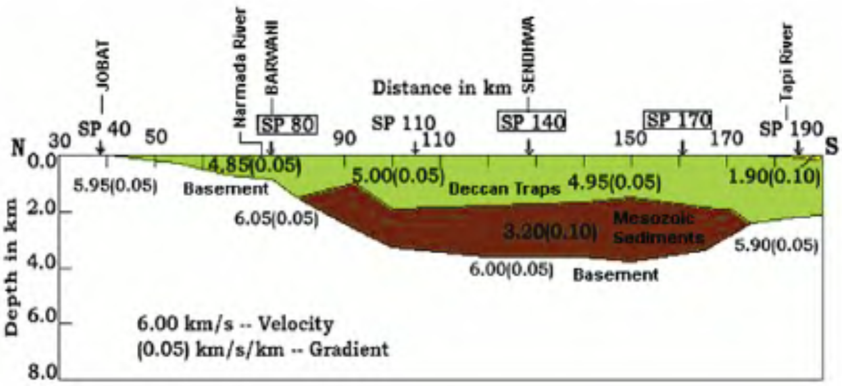

Figure 5. Final 2D velocity depth section showing the Mesozoic sediments sandwiched between the Deccan traps and the basement.

deepest sediments are seen sandwiched between two other formations. The thickness of the sedimentary layer is ~2400 m starting from a depth of about 2 km. The basement velocity is around 6 km s^{-1} while the trap cover has a velocity of 5 km s^{-1} and the velocity of the sedimentary layer is found to be 3.2 km s^{-1} terminating at the basement. The velocity gradient is 0.05 km/s/km in the trap covered region and about 0.10 km/s/km in the alluvial column and in the hidden Mesozoic layer. The velocity gradient in the basement is 0.05 km/s/km.

SP 170 is the last shot point of the profile, which samples the sedimentary layer. Since the LVL shown in Figure 4 thins out towards the terminal shot point SP 190, it can be concluded that the LVL is absent below the SP 190. The derived velocity model for which the computed travel times and synthetic seismograms match the original data reasonably well is considered as the final velocity model (Figure 5) for the study area.

On geological considerations, Mesozoic sediments are considered potential reserves of hydrocarbons. Noting that detection of LVL associated with the Mesozoic sediments under the high velocity Deccan volcanic cover, a very meticulous analysis of the DSS data has brought out the evidence of the basinal structure, filled with low velocity sediments between Narmada and Tapti rivers. The ray tracing technique[9] has given a strong evidence for the presence of Mesozoic sediments in the study area. A revisit to this seismic data has brought new constraints on the structural setting of the most conspicuous tectonic feature of India.

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