

## APPENDICES

### Appendix - 1

Geo-technical investigation reports by GSI

GOVERNMENT OF INDIA  
**GEOLOGICAL SURVEY OF INDIA**



**PRELIMINARY GEOTECHNICAL REPORT ON POTTIPURAM SITE ( $\Delta$  1589)  
FOR LOCATING UNDERGROUND LABORATORY OF  
INDIA BASED NEUTRINO OBSERVATORY,  
THENI DISTRICT, TAMIL NADU  
(Field season 2009-10 & 2010-12)**

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### ABSTRACT

*As an alternative to earlier proposal for locating INO Cavern at Singara in the Nilgiri Mountains, INO authorities have selected Tevaram (Pottipuram Site) in Kambam valley of Theni district for preliminary study. The site specific geological study of the Pottipuram hill ( $\Delta$  1589) to locate the INO lab cavern was carried out with special emphasis on Access tunnel. The hill exhibits massive rock outcrop from bottom to top and beyond. Tunneling media (charnockitic gneiss) is hard, fresh with 3 to 4 sets of joints. Vertical and subhorizontal joints are prominent and their intersection has created scarps. This has resulted in the steep rock profile of the hill. In general the rock mass quality appears to be 'Good' and tunneling is prognosticated to be smooth requiring some light support like rock bolt, shot crete, etc. in the low cover reaches. In the high cover reaches, high stress conditions may cause rock bursts. No major adverse geological features are inferred. Geological sections were prepared for two alternative alignments of access tunnel and compared. Geologically alignment - 2 is preferable. However, due to land acquisition problem, project authorities preferred the alignment -1. Hence, further study and exploration has been carried out for the alignment-1. In the portal area seven boreholes were drilled and they were logge. The geotechnical analysis indicated that the portal area of access tunnel will have thick overburden up to 23.50m and rock profile is not uniform up to the hill boundary .Based on the analysis, different reaches for opencut, soil tunneling and fresh rock tunneling are recommended in this report.*

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## **I. INTRODUCTION**

As an alternative to earlier proposal for locating INO Cavern in the Nilgiri Mountains at Singara close to the PUSHEP of TNEB, INO authorities have selected three sites, viz., Suruliyar, Tevaram and Kottagudi in Kambam-Bodi Valley, Theni District, Tamil Nadu. These three sites were studied by GSI and a report was submitted during October 2009 (Srinivasan, 2010).

Out of the three sites, INO group has selected Tevaram (Pottipuram Site) for detailed study. Subsequently TNEB has been entrusted with the job of preparing DPR for the Pottipuram area. As requested by SE/Projects, TNEB, Chennai, the site was studied from 24.03.10 to 25.03.2010, on 28.04.09 and from 5.10.10 to 6.10.10 in the presence of INO project leader and TNEB site engineers.

## **II. STUDY AREA**

The proposed site is located on the eastern fringe of the linear Western Ghat hills and is close to the Tamil Nadu - Kerala State boundary (Plate-1). The escarpment face of the hill ends up against the plains of Kambam Valley in Tamil Nadu. The hill has vertical scarps at different levels intervened by moderate slope of about 35° to 40°. The foot hill has access from its eastern peripheral plains of Tamil Nadu.

Three possible alignments of the access tunnel to the lab cavern were identified (Plate-2). In all the three alignments, only portal area and initial reaches of the access tunnel alignment were studied because, rest of the reach is not accessible as the hill is too steep. Hence, the remaining reaches of the access tunnel up to the hill peak were observed only from a distance.

## **III. GEOLOGY**

In the previous report submitted to the INO Group, geotechnical analysis of this Pottipuram hill was discussed with a geological plan and cross section (Srinivasan, 2010). Detailed examination of the rocks exposed in the foot hill shows that the hill is made up of



charnockitic gneiss and migmatite with small enclaves of mafic rocks such as amphibolite and pyroxene granulite. In general, the lithology is homogenous in the eastern slope and charnockitic gneiss is predominant. Veins of (1 to 1.5 m wide) pegmatite intruding along the joints are seen in the southern part of the hill and the northern part appears to be relatively more massive than the southern side. The foliation of the rock is trending in N 20° to 45° E – S 20° to 45° W direction and dipping at 70° towards SE (valley side). But, foliation strike and dip changes due to folding and migmatitic flowage. Other than the foliation parallel joints, the following are major joint sets in the order of prominence

1. N 80° E – S 80° W – Subhorizontal joints.
2. N 40° to 60° E – S 40° to 60° W, dip 60° towards N 30°-50°W (60 cm to 1.5 m) with pegmatite emplacement.
3. N 20° W – S 20° E – Vertical (spacing: 0.5 to 1.0 m).
4. N 20° E – S 20° W – dip 80° towards N 70° W.

No major shear zone or dyke are seen in the foot hills. However, the regional geological map shows a shear zone trending NNE-SSW and traversing the alignment -1 of access tunnel in middle reaches

## **VI. GEOTECHNICAL EVALUATION**

The hill slope is rocky from peak to plain and is covered with sparse forest vegetation in patches. The nature of rock and its geotechnical characteristics seem to be in general uniform all around the peak. The rock outcrops at the eastern side of lower slopes were only examined and the observations are extrapolated to higher reaches due to limited access. The slope on the eastern side has steep scarps and vertical rock cliffs seen particularly on the southern side. It is presumed that the scarps are formed due to erosion and dislodging of rock blocks due to the intersection of horizontal and vertical joints and not by any tectonic features like faulting. In the regional geological map of GSI, a major NE-SW trending (parallel to foliation), weak plane – shear zone - is shown in the mid-slope at the foot of the scarp (plate- 5 & 6). However, no shear zone is observed in the lower slopes parallel or sympathetic to the feature shown in the map. Probably it is an interpreted weak zone projected to the hill. It appears to intersect the access tunnel in middle reaches and not the cavern portion.

Rock mass of the hill is homogeneous in general and thin pegmatite veins transect the rocky mass along the joints. Foliation and three to four prominent joint sets are the

discontinuities seen. Joint spacing is moderate. Hence, RQD might be high and rock mass quality can be rated as “Good”. No major adverse geological features are anticipated and excavation is expected to be smooth for Access tunnel and lab cavern excepting problems posed by high stress conditions.

Analysis of regional geological data indicates the presence of a few crustal weak zones on regional scale in close proximity or within 50 km range. Prominent weak zones are in NE/SW (Suruliyar Lineament) and NW/SE (Periyar and Kerala Lineament) directions. GSI conducted Active Fault studies of Suruliyar Valley and concluded that the existing micro seismic (<3 Magnitude) activities are along the NW/SE direction, even though Suruliyar Lineament is oriented in a NE/SW direction. Second generation geological maps (1:25,000 scale) prepared by GSI in the Uttamapalayam and Kambam areas also shows the presence of Faults in NE/SW (Major) and NW/SE (Minor) direction. In view of these observations, it is prudent that seismic coefficients for moderate magnitude earthquakes (Magnitude 5) is provided while designing the detector in the lab cavern. Seismic aspects are dealt in the report submitted earlier.

#### **A. CHARNOCKITE AS A TUNNELING MEDIUM**

Various physio-mechanical properties of charnockite occurring in Pykara Ultimate Stage Hydroelectric Project (PUSHEP) as determined by National Institute of Rock Mechanics, Kolar Gold Fields are as follows:

1. Density (gm/cc)	:	29
2. Unconfined Compressive Strength (Mpa)	:	179
3. Young's Modulus (Gpa)	:	97
4. Poisson's Ratio	:	0.27
5. Tensile Strength (Mpa)	:	13
6. Cohesion	:	42
7. Friction Angle (deg.)	:	47.5
8. Constant 'm'	:	25.1

In view of its highly favourable physico-mechanical properties and wide distribution, charnockite enjoys the status of a leading construction material in the states of Tamil Nadu and Kerala.

Underground excavations in PUSHEP were carried out by conventional drilling and blasting methods. Barring a few isolated short reaches, the tunnels and shafts were self supporting (Pitchai Muthu, 2002). A 'Q' value of about 45 was worked out for most of the

reaches of the tunnel. The underground powerhouse cavern of PUSHEP under a rock cover of over 500m withstood the high stress conditions. Based on the past performance of tunnels excavated in charnockite in the region, permanent supports were provided at the barest minimum. Similar geological setting is expected at INO cavern also and the only concern would be the >1000 m of rock cover which would create stress related problems like rock bursts.

## **V. ACCESS TUNNEL ALIGNMENTS**

Three alignments were considered for Access Tunnel to INO Lab cavern (Plate 2). One alignment in southern side, in the direction of N 32° W – S 32° E, another at the centre in the direction of N 68° W – S 68° E and third at the northern side in the direction of S 80° W-N 80° E were studied in the field. Emphasis was given to portal location as the hill slope is rocky and forest boundary begins mostly at the beginning of the hill.

All the three alignments have the similar surface profile of rocky hill slope starting from plain area covered with overburden. Forest boundary in all the three alignments coincides with the rock boundary. The project authorities wanted to avoid forest land while locating the portal. Hence, it has become mandatory that the portal is established away from the forest land. This has necessitated the location of portal in the open plain land with a provision of cut & cover or open cut till sufficient hard rock cover for tunnel is obtained.

Of the three alignments (Plate-2), alignment -3 located on the northern side (North of village temple) has to be approached through private land. Moreover the presence of deep and narrow nala in N-S direction is also restricting the access to alignment even though no geological problems are noticed in alignment- 3.

Hence only alignment 1 and 2 were studied in detail. As no detailed contour map or longitudinal section is available, enlarged topo sheet on 1:25,000 scale was used in the analysis. In both the alignments the tunnel length is same at 2,150 m and gradient of 1 in 15 is proposed for the 7.5m dia tunnel.

### **A. ALIGNMENT 1**

The portal area and initial reaches of the alignment were studied by taking geological traverses. The site observations show that the proposed portal in the open scrub in between two small nalas may have 6 to 7 m thick overburden. Weathered rock outcrops are noticed in the stream course located further down slope, with 7 m thick soil cover (depth of the valley is 7 m). This soil covered open scrub area with a very gentle slope is about 260 m long from RL 430m to

the rim of the rocky hill along the proposed alignment. Beyond this soil covered area, the profile becomes steep and rock out crop starts appearing from RL 450. From this chainage, the rock outcrops are continuing all along the alignment with exception of a few spots where the hill slope is covered with thin scree material. Thus, the tentative rock profile in soil covered reach is drawn by connecting the rock outcrops in stream bed and at the rim of hill. With the available information a geological section (LS) was prepared based on the profile provided by the project authorities (Plate-3). The details are summarised in the Table-1

**Table-1 Rock cover estimation for alignment -1 of Access Tunnel**

S. No	Description	Ch in (m)	Ground Level (m)	Assumed Weathered Rock Level (m)	Crown Level of Tunnel (m)	Total Cover (m)	Rock cover available (m)	Remark
1.	Stream Bed	(-) 100	425	425				
2.	Stream Bank	(-) 90	430	425.4				
3.	Beginning of open cut	0	435	428				
4.	Tunnel Portal	185	448	445	430.5	17.5	14.5	
5.	Sheet Rock Exposure	225	450	450	427	23	23	
6.	Forest Boundary	250	465	465	426	35	35	

It indicates that from Ch. 0-50 m excavation will be in loose soil and from Ch. 50 m to 185 m the excavation will be partly in soil and partly in weathered and hard rock. Thus an open cut or cut & cover for a length of 185 m is envisaged in this alignment.

## **B. ALIGNMENT - 2**

It is located in central part of eastern hill slope. A prominent rock spur is seen in the hill slope in this area and the alignment 2 is proposed at the southern side of this spur in the direction of N 68° W – S 68° E.

It has a comparatively gentle gradient in the lower slopes of hill. Similar to alignment 1, the rock out crop boundary of the hill coincides with forest boundary and beyond which the open plain area is there with soil cover. A few weathered rock out crops are seen in the open plain in the area. Surface geological studies indicate that weathered rock is occurring at shallow depth of 2 to 3m adjacent to forest boundary. The assumed rock line is formed by joining the rock



out crops and rock out crops at the hill. The geological section ( Plate-4) shows that the open-cut or cut & cover section would be about 160 m long and mostly in weathered and fresh rock which is considered a favourable feature compared to excavation in loose soil. A brief summary of the observations made along this alignment is in table -2.

**Table -2 Rock cover estimation for alignment -2 of Access tunnel**

Sl. No	Description	Ch in (m)	Ground Level (m)	Assumed rock level (Weathered Rock Level)(m)	Crown Level of Tunnel (m)	Over burden (m)	Rock cover available (m)	Remark
1.	Beginning of open cut	0	430	427				
2.	Tunnel Portal	165	442.5	441.5	426	16.5	15.5	
3.	Forest Boundary (sheet rock exposure)	237	450	450	421	29	29	

### C. SELECTED ALIGNMENT AND ITS GEOTECHNICAL EVALUATION

The project authorities preferred Alignment no-1 for the access tunnel due to land acquisition problems in other alignments. A site visit was made to study in detail the portal area of this alignment and to suggest subsurface exploration. During this study, geological traverses were taken along the proposed alignment, particularly in the portal area. A slight shift towards north was made in the alignment -1 as the previous alignment had its open-cut area in the forest land. After marking the access tunnel alignment on the ground, bore hole locations were fixed for subsurface exploration.

The hill slope is rocky from lower reaches to peak along this alignment. Examination of rock outcrop in the lower slopes of access tunnel alignment shows the presence of massive to moderately jointed charnockitic gneiss with pegmatite intrusion. The rock has foliation in the direction of N20° to 45° E - S20° to 45°W dipping 70° towards SE. Subhorizontal joints trending N80°E-S80°W with thin pegmatite veins is predominantly seen in the vertical rock scarps. The joints are widely spaced. In addition NW/SE trending vertical joints are also seen. The foliation of the rock and pegmatite veins are at acute angle to the alignment of access tunnel which is oriented in N32°W-S32°E.

It was observed that the inlet area of the alignment is located between two small nalas and may have 7 to 8 m thick overburden. The stream on the southern side has about 6 to 8m deep

valley with weathered rock outcrops on the valley floor. The northern side nala is small with little incision. The rock outcrops in the hill extend close to the forest boundary. The other areas further downstream of forest boundary along this alignment has a gentle pediplain with sparse vegetation. No rock outcrops are seen in this open scrub area and it is fully soil covered. The Access tunnel portal is carefully planned to avoid forest land.

Along the alignment-1, to know the exact bed rock depth and to fix the portal of Access tunnel, subsurface exploration was recommended. Along the alignment four boreholes located at 7 m, 57 m, 132 m and 172 m from reserve forest pillar no. 31A of forest boundary were recommended to be drilled up to 7 m depth into the fresh rock with more than 80% of core recovery.

#### **D. SUBSURFACE EXPLORATION OF PORTAL AREA**

As recommended by GSI four bore holes were drilled by the project authorities. In addition three bore holes were drilled by the TNEB. Thus, seven bore holes were logged after making the site visit in the initial reaches of the access tunnel proposed for INO cavern.

During core logging, it was found that the cores were not arranged run-wise and no depth marking was done for each run. Only a cumulative depth for certain runs given. Many samples did not have arrow marking indicating the direction of depth. Driller's log sheet doesn't indicate water loss or water colour details. This has resulted in the approximate fixing of weathered rock and fresh rock levels. Abstract log of bore holes cores is given in Table - 3 and detailed log in the annexure. A geological section prepared with the data is available in Plate-7.

Table -3 - Abstract litholog of bore holes drilled in Alignment-1 of access tunnel

B.H. No.	Location (m)	Total Depth Drilled (m)	Ground Elevation (m)	Weathered (moderately weathered) rock level	Fresh Rock Level (m)	Lithology and other details
BH- 1	Ch.0	33.79	432.40	416.80	413.62	0 to 5.80m - Soil. 5.80m to 15.60m - completely weathered rock with small rock fragments. 15.60 to 18.78m - moderately weathered mafic rich hornblende biotite gneiss. From 18.78m onwards fresh charnockite with high core recovery and RQD. Rock is massive and joints are few.
BH- 2	Ch.41.50	35.05	435.40	-	-	The bore hole was drilled all through its depth in soil and completely weathered rock only. Fresh rock was not met. (No sample is preserved beyond 9m depth).
BH-2A	Ch.44.50	28.00	435.55	412.05	408.15	0 to 23.50m: Soil and completely weathered rock.(sample preserved only up to 9.00m depth). 23.50 to 23.70m pink pegmatite moderately weathered. 23.70 to 27.40m gneissic rock moderately weathered with core loss in between. From 27.40m onwards fresh rock with long core indicating high core recovery and RQD.
BH-2B	Ch.82.00	25.36	437.900	423.90	416.37	0 to 14.00m: Soil and completely weathered rock (sample preserved only up to 3m), 14.00 to 17.86m -Hornblende biotite gneiss, moderately weathered. 17.86 to 19.41m - pink granite moderately weathered. 19.41-21.53m core loss. 21.53m onwards fresh charnockite with high core recovery and RQD.
BH-3	Ch.122	29.25	441.200	423.42	419.27	0 to 17.27m- Soil and completely weathered rock (sample preserved up to 9.30m). 17.27 to 17.78m boulder. 17.78 to 19.53m- charnockite slightly weathered, 19.53 to 20.43m - core loss. 20.43 to 21.13m charnockite moderately weathered. 21.13 to 21.93m pegmatite moderately weathered. From 21.93m fresh and massive charnockite with high core recovery and RQD.
BH-4	Ch.170	25.00	446.070	427.07	424.92	0 to 19.00m - Soil and completely weathered rock (sample preserved up to 17.00m). 19.00 to 20.21m-charnockite moderate to highly weathered. 20.21 to 20.90m - charnockite slightly weathered. 20.90 to 21.15m -charnockite moderate to highly weathered. From 21.15m onwards charnockite fresh rock with high core recovery and RQD.
BH-4A	Ch.215	11.56	452.79	452.39	452.33	0 to 0.10m-Soil, 0.10 to 0.40m completely weathered rock, 0.40 to 0.46m moderately weathered charnockite. 0.46 to 7.74m fresh and massive charnockite. 7.74 to 11.56m fresh and massive granitic rock with high core recovery and RQD

The study has revealed that fresh rock is not available at uniform depth in the holes. There is a sudden variation in the rock level between bore hole 4 and 4a (higher at 4A) and there is a fall in the rock level to a depth of 27.41m within 45m distance. Then at BH-2A fresh rock level is 408.15m which is deeper compared to the adjacent bore holes of BH1 and BH 2B. Surprisingly the BH-2 did not meet fresh rock up to 35.50m and this is an anomaly. This bore hole detail is not taken into consideration in preparing the geological section and further analysis.

The observations made in rocky slope between the bore hole no-4A and the first vertical cliff showed the presence of weathered granite gneiss. Two additional bore holes were recommended in the above described area to know whether the weak rock is persisting at depth as the weathering pattern is seen to be irregular in the study area. The project authorities informed that they could not obtain forest department clearance to drill these bore holes.

Logging of cores of boreholes drilled indicated that invariably the fresh rock at depth is charnockite which is massive and less jointed. The recovered cores are long. It has high core recovery percentage and RQD. Thus the tunneling medium in the drilled area at depth has 'Good' rock mass quality. It is overlain by pink granitic rock which is amenable for weathering more easily. The profuse intrusion of granite with closely spaced subhorizontal joints probably along the margin of Suriliar -Kambam shear zone is the rock characterisation in the portal area of access tunnel alignment. A “step like” surface profile and bed rock configuration may be due to faulting and granite emplacement.

With the available data a geological section was prepared (plate -7) and the following observations are made for the initial reaches of access tunnel:

1. The **open cut** may start at Ch.66m at El. 436.60m and extend up to Ch.146m considering the forest boundary which shall not be encroached upon.
2. By creating a face at Ch.146m, **soft rock/soil tunneling** can be undertaken with concurrent rib support up to Ch.186m.
3. **Fresh rock** in full face of **tunnel** is expected from Ch. 186m from where drilling and blasting is possible.
4. The tunnel would **cross the forest boundary** below **overburden cover of 14m** which is considered adequate for soil tunneling with concurrent rib support.
5. The tunnel portal and the cut slope over the portal are to be adequately supported before resorting to soft rock tunneling. For tunneling in soil, techniques like **Fore poling/ heading and benching** as suitable may be adopted.



6. Size of the tunnel may be optimized because, large sized tunnels face more problems during construction and also increase the cost.

## **VI. CONCLUSION AND RECOMMENDATIONS**

1. The site specific geological study of the Pottipuram hill ( $\Delta 1589$ ) to locate the INO lab cavern was carried out with special emphasis on Access Tunnel. The rock mass characteristics of the hill appear to be homogeneous all around the hill. No major adverse geological features are seen. Tunneling media (charnockitic gneiss) is hard and fresh with 3 to 4 sets of joints. Rock mass quality appears to be 'Good' and tunneling is prognosticated to be smooth with some light support like rock bolt, shot crete, etc. in the first half. In the high cover reaches of second half, high stress conditions may cause rock bursts and the problem has to be tackled by adopting suitable technique in tunneling.
2. Three alignments were examined for access tunnel out of which two were studied in detail (1 and 2). Alignments 1 and 2 have gentle plain area followed by rocky hill slope.
3. The bed rock depth is shallow in alignment 2 (2 m from surface) and it is comparatively deeper in alignment - 1 (7 m from surface) at the proposed portal. In view of this, geologically alignment - 2 is preferred. However, during discussion with the TNEB and INO officials on 07.04.10 at GSI office in the presence of Director, GSI, it was informed that the portal location of alignment-2 falls in the private land and land acquisition would be a problem. In case of alignment -1 the portal is located in the Government land, they informed. Hence, further study and exploration is recommended for the alignment-1 as the preliminary study results are not adverse to this alignment.
4. Along the alignment-1, to know the exact depth to bed rock and to fix the portal of Access tunnel, subsurface exploration was recommended. Four boreholes located 7 m, 57 m, 132 m and 172 m from Pillar No.31A of reserve forest boundary were drilled.
5. TNEB authorities drilled three more bore holes on Access tunnel alignment and all the cores were logged. The study has revealed that depth to fresh rock is not uniform and there is a sudden variation in the rock level between bore hole 4 and 4a where there is a difference of 27 m in rock level within 45m distance. The over burden thickness in the drilled area varied from 0.40m to 23.50m.
6. The fresh rock at depth is charnockite which is massive with few jointed and the rock mass quality is 'Good'.

7. With the available data a geological section was prepared and reaches for open-cut, soil tunneling and fresh rock tunneling were identified as follows:
  - a. Ch. 66 to 146 m: Open cut
  - b. Ch. 146 to 186 m : Soft rock / soil tunneling with Portal at Ch.146 m and
  - c. Ch. 186 m onwards rock tunneling.
8. The preliminary study results are favourable to the site. A detailed contour map of the proposed alignment with 2m contour interval from inlet to hill peak and 'L' section are to be prepared by the project authorities for detailed study.

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Director  
Engineering Geology Division  
Geological Survey of India

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**Plate-1**

**LOCATION MAP OF I N O PROJECT SITE, POTTIPURAM**

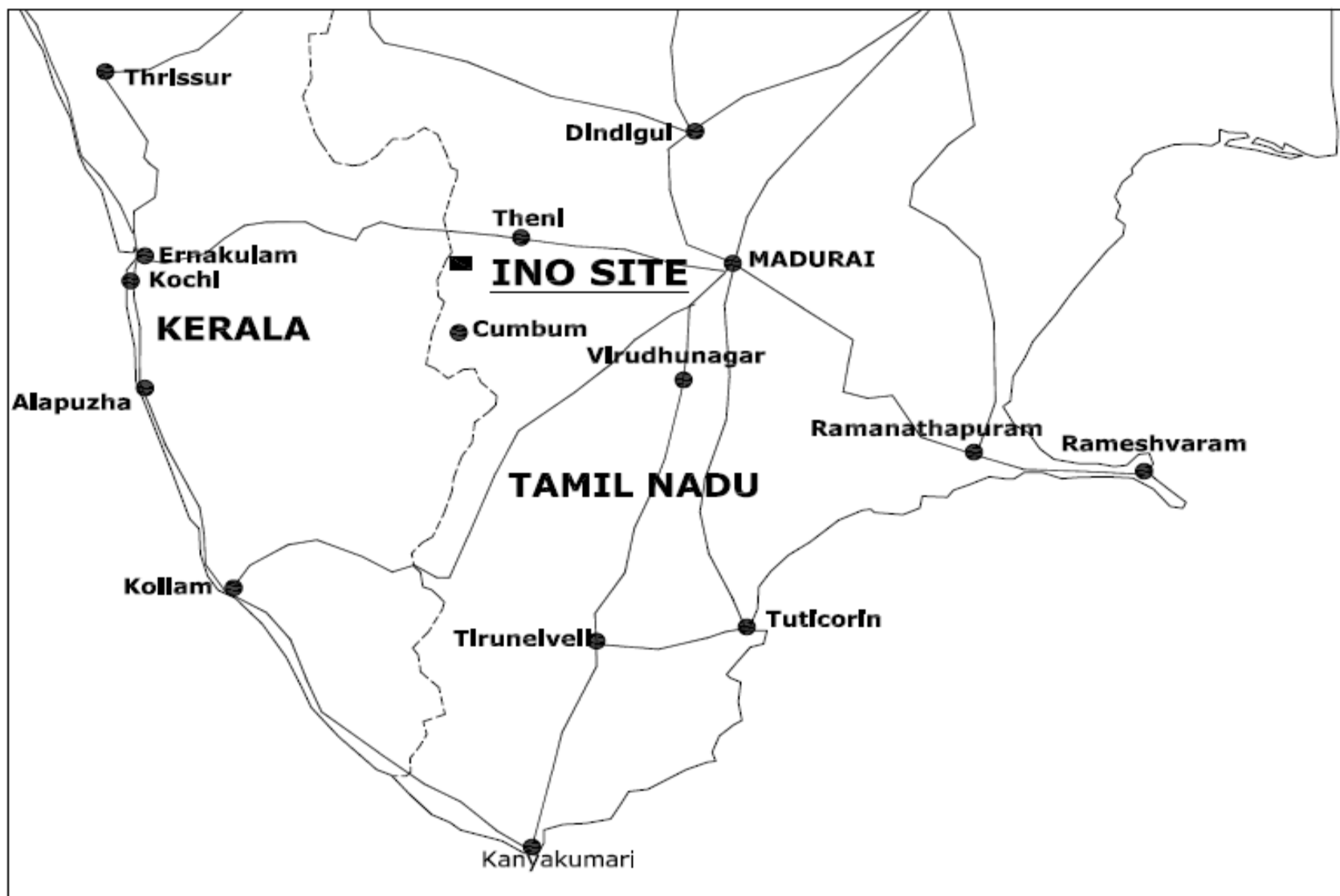
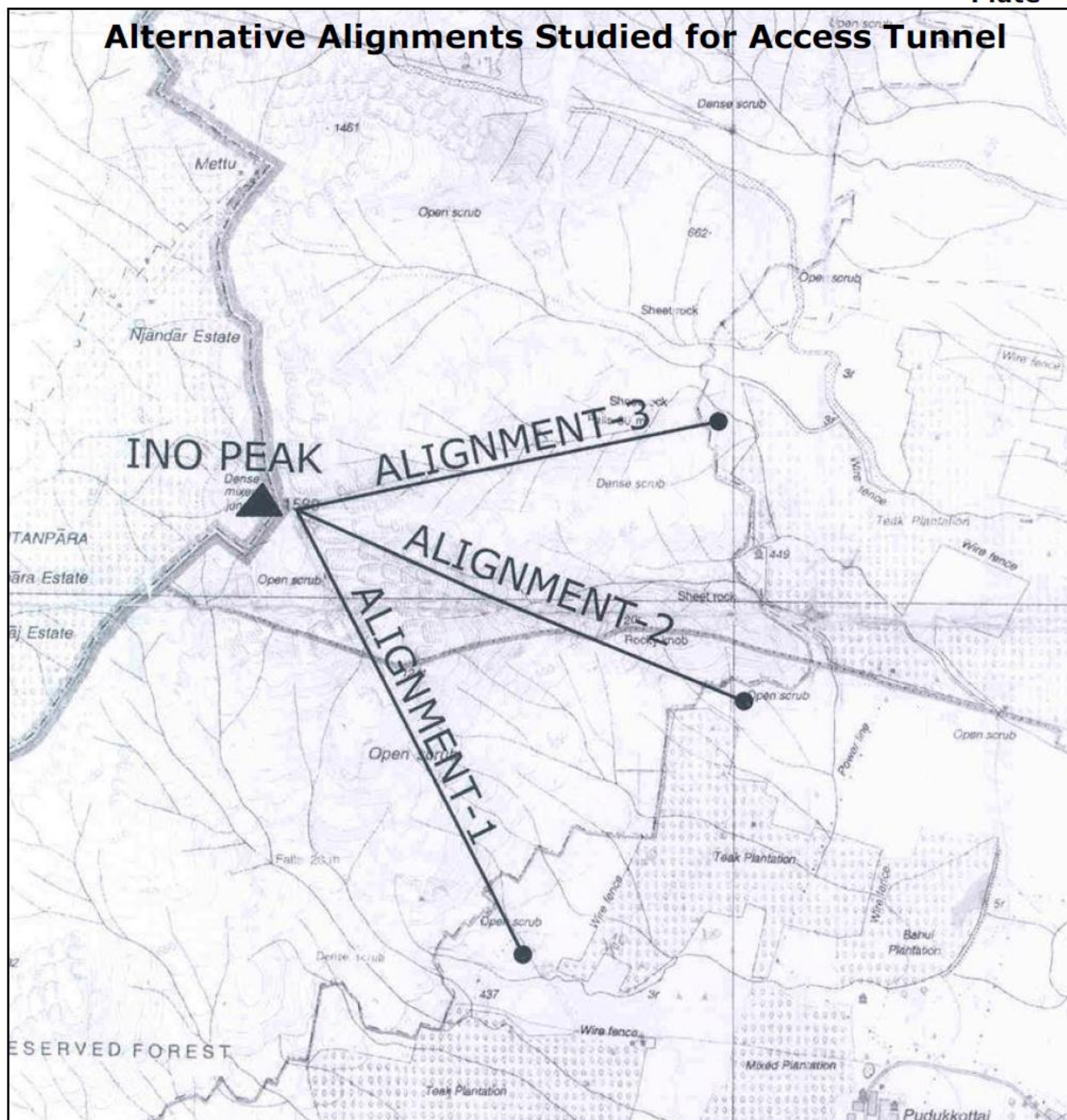


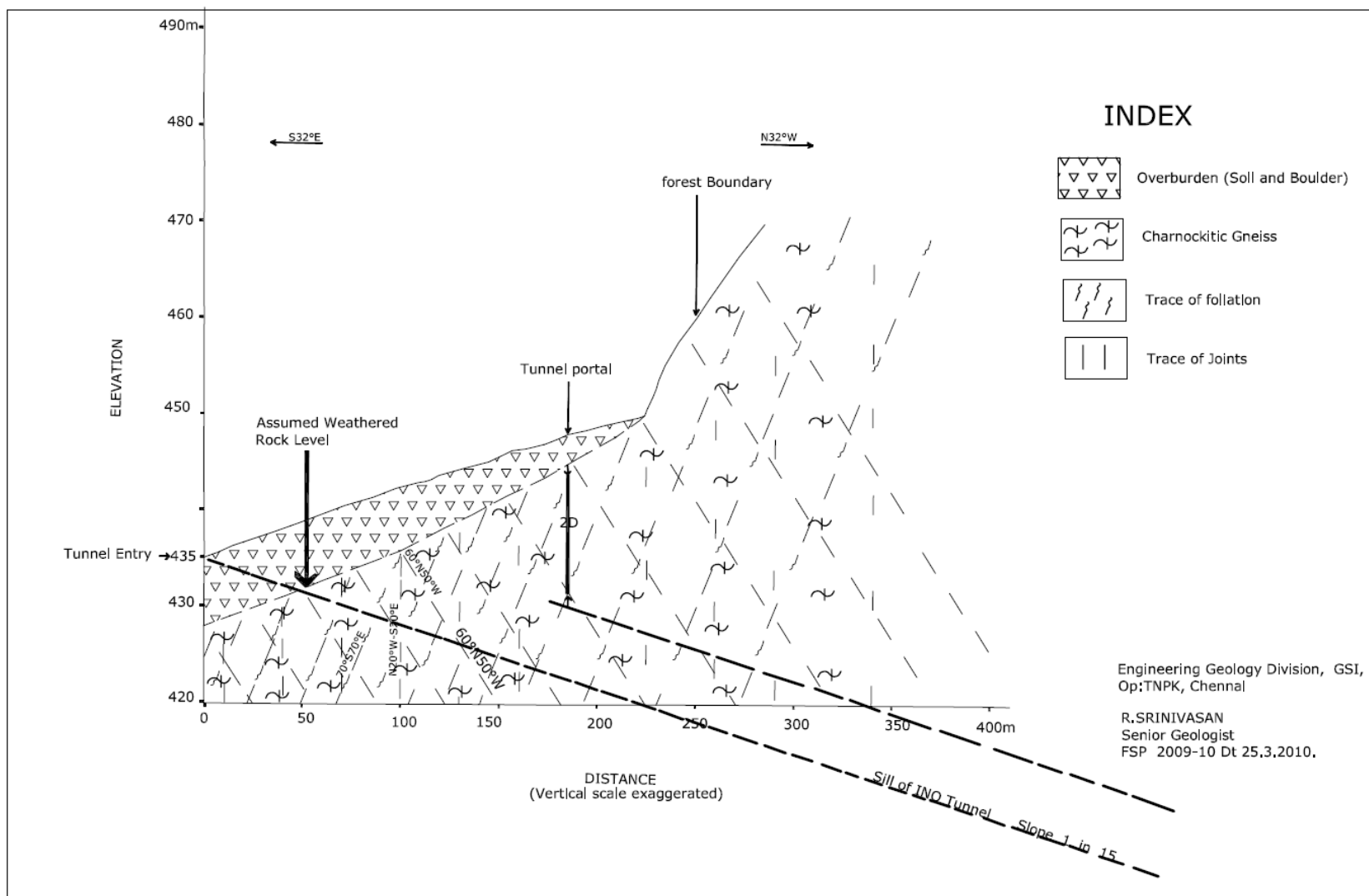
Plate - 2



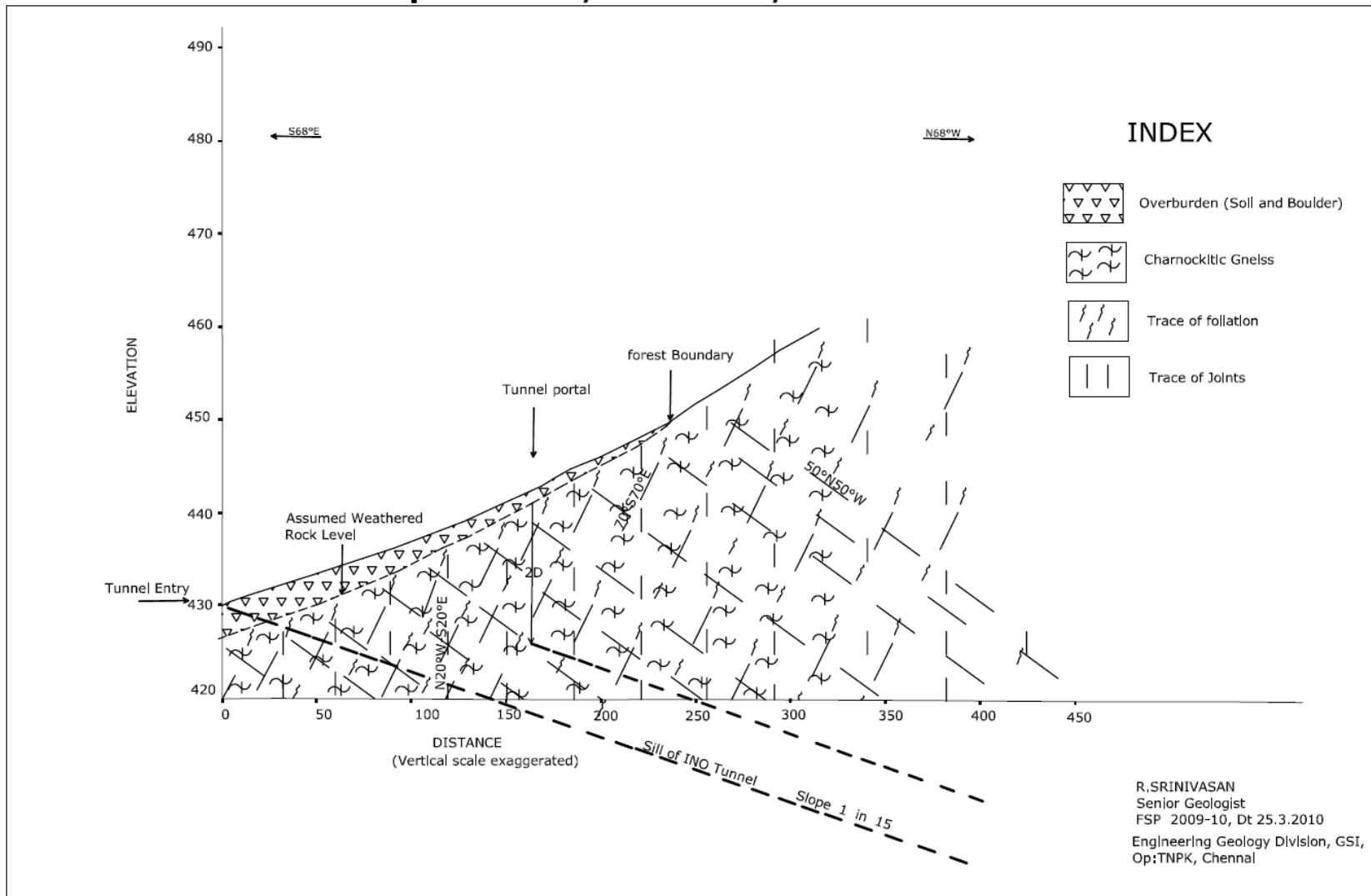


**INO ACCESS TUNNEL ALIGNMENT-1**  
**Tentative Geological Section along the INO Access Tunnel alignment - 1**  
**Pottipuram Hill, Theni Dist, Tamil Nadu**

Plate - 3



## Tentative Geological Section along the INO Access Tunnel alignment - 2 Pottipuram Hill, Theni Dist, Tamil Nadu



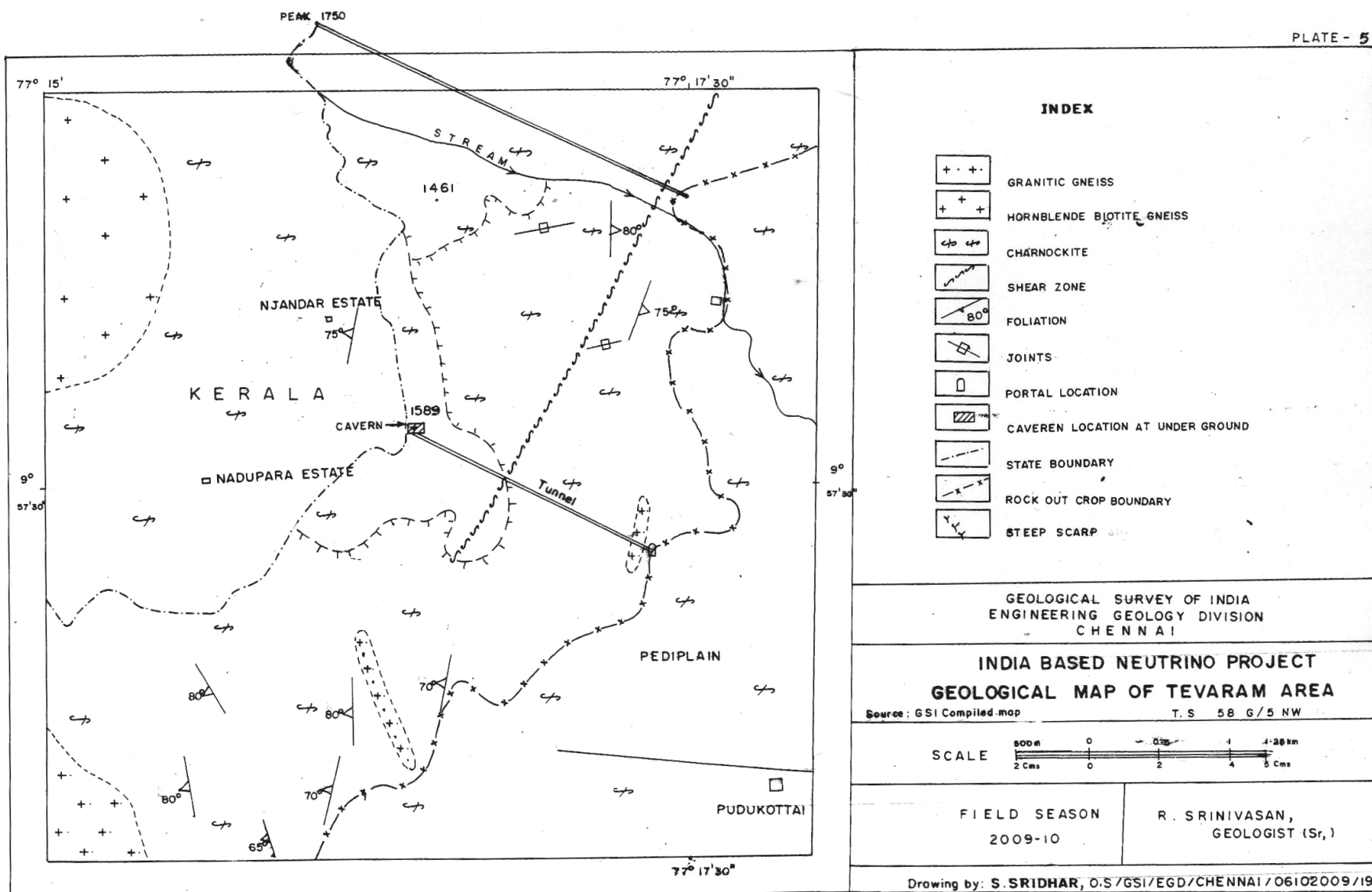
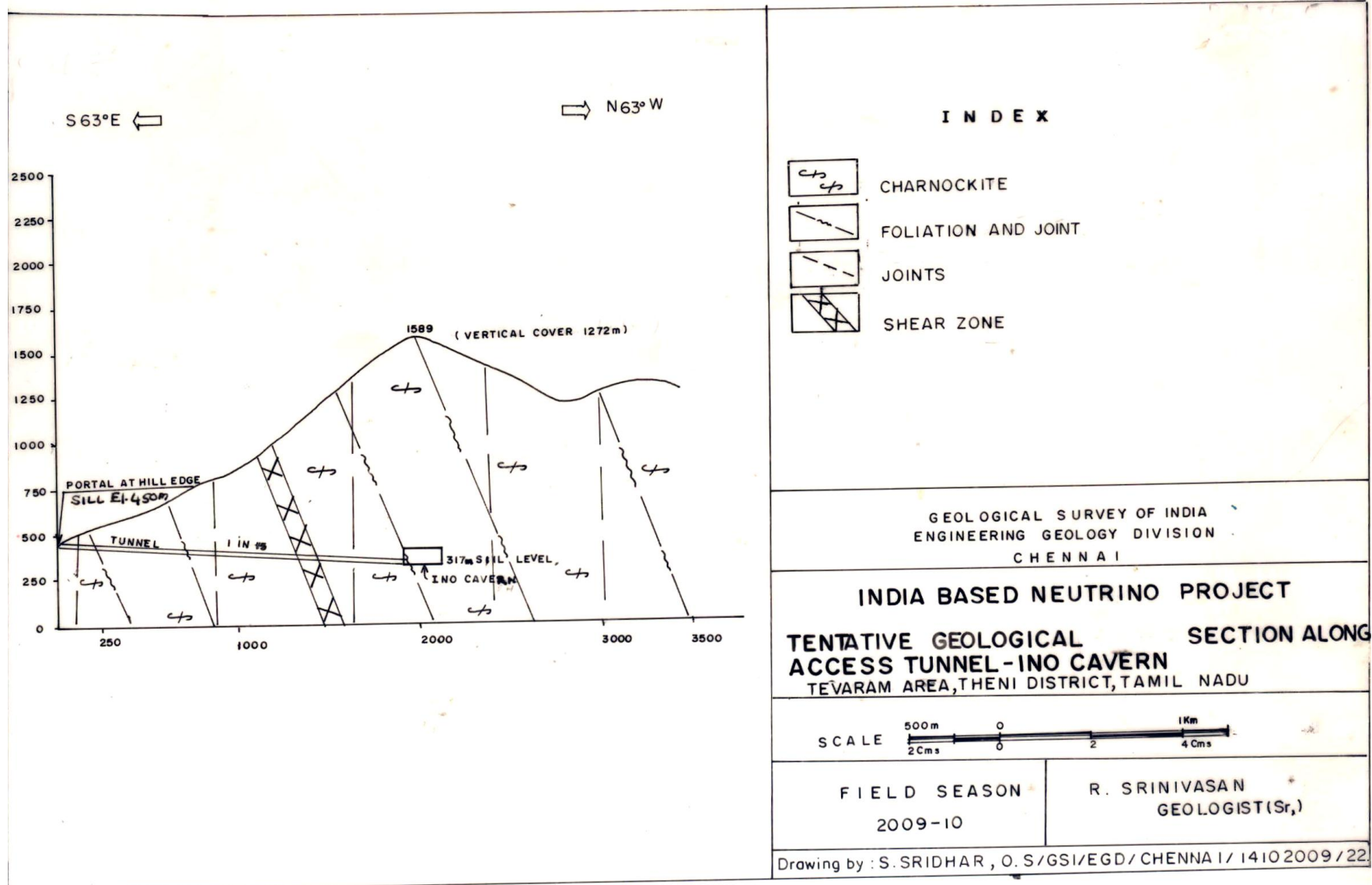


PLATE - 6





**INDIA BASED NEUTRINO OBSERVATORY PROJECT  
POTTIPURAM, THENI DISTRICT, TAMIL NADU**

**GEOLOGICAL SECTION FOR THE PORTAL REACH OF ACCESS TUNNEL  
(Alignment-1)**

Plate- 7

