THE LAB IN THE WOMB OF A WHIRLING WORM

INDIA BASED NEUTRINO OBSERVATORY, SHEAR ZONE, AQUIFER AND TECTONICS

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Abstract

The proposed India-based Neutrino Observatory (INO), the largest underground science laboratory in the world, with a finished volume of 235,000 m^3, will be blasted out in Idukki- Theni mountains of the Western Ghats. The proposed site is in the highly deformed portion of the the Suruli ductile Shear Zone. There are 12 reservoirs within 50 km radius of the complex, storing about 5 billion m^3 of water. Idukki is the water capital for five severely water-stressed districts in Tamil Nadu and Kerala. The 'geotechnical' study report (GTR), based on sparse and low quality primary data has been treated as a confidential document. The impacts of blasting 800,000 tons of rock on the aquifer, the rivers and the reservoirs were not among the endpoints of the geotechnical study. Besides responding to the INO scientists and a geo-engineer, here we extend our arguments against the project with a critique of the GTR, a summary

of studies on hydro-geology of the region, visible impacts of mountain tunnelling in India and elsewhere and the regulatory regime that is evolving globally. Starting the construction without conducting a proper, scientific impact assessment may be suicidal. We also doubt whether the physics requirement of filtering the cosmic background radiation, essential for a neutrino detector, will be possible at the present site.

Keywords: Mountain tunnelling, neutrino observatory, hardrock aquifer, tunnelling shear zone, environmental impact assessment, geotechnical study, global catastrophic risk

1. Introduction

Water has been a political issue for a long time and scientists and politicians are working to avert a water-driven world war. Recently, "human-induced earthquakes have become an important topic of political and scientific discussion" due to "an overall increase in seismicity"[1], says William Ellsworth in his paper on anthropogenic seismicity. In this background, we are grateful to BS Acharya and 21 phenomenologists (Acharya et al)[2] and V Balachandran[3], engineering geologist for joining the debate on the potential hydro-geological impacts of mountain tunnelling for construction of the India-based Neutrino Observatory (INO), the world's largest underground science laboratory with a finished volume of 235,000 m^3 n Idukki-Theni districts of Kerala-Tamil Nadu in the Western Ghats. Citing the experiences of the Gran Sasso National Laboratory (LNGS) in Italy, two of us (VTP and MJ)[4] had argued that blasting out 800,000 tons of rock, using about 1000 tons of explosives may impact the aquifers and reservoirs on the Periyar and the Vaigai river systems, which are the lifelines for over 10 million people in five districts of Tamil Nadu and Kerala states. Acharya et al and Balachandran stated that the site was chosen after a detailed geotechnical study (GTS) and ruled out any negative impact on water resources. We thank Prof NK Mondal for providing a hard copy of the GTR which which he said is a confidential document. This document only strengthens our argument regarding the impacts of tunnelling on the water resources.

2. Role of Science in Site Selection

2. 1 Brief history of the project

A brief history of the project will reveal the role of science in site selection. On 20 November 2009, the Central Ministry of Environment and Forests (MOEF) denied the first site selected by INO in the Nilgiris due to its proximity to a tiger sanctuary.[5] MOEF's offer of Suruliyar in Theni district which was under INO's consideration since February 2009 was rejected "because there were less available data on the characteristics of the rock that would need to be blasted"[6]. "Thevaram, the present site, surveyed during 29-30 September 2009"[7] was opted even though the site related information was sparser than that for Suruliyar. In INO's own words, at Thevaram the "rock quality appears to be good, but should be confirmed through detailed geotechnical studies–local variations may be important".[7] 'Public hearing' for the Thevaram site was held on 9 July 2010[8] and the MOEF approved the site on October 19, 2010[9]. The Salim Ali Centre for Ornithology and Natural History (SACON) completed the Environmental Impact Assessment (EIA) in November 2010.[17] R. Srinivasan of the Geological Survey of India (GSI) Chennai finalized the GTS report on 14 December 2010.[10] The role of the 'EIA scientists is clear from this narrative. On December 28, 2012 the district administration handed over 27 ha of grazing land in Pottipuram Panchayat of Theni district to the Indira Gandhi Centre for Atomic Research, Kalpakkam of the DAE[11] for construction of surface facilities.

2. 2 Critique of INO's Geo-technical Study

INO's geo-technical report (GTR) was first mentioned in an opinion piece in a newspaper on 8th Oct 201212. The INO spokesperson also mentioned about it during a talk at Thiruvananthapuram 10 days later.”13 The GTR is a confidential document and as an unusual gesture, the Tata Institute for Fundamental Research (TIFR) provided a hard copy of it in April 2013. (An OCRed version of this is placed as a supplementary document.) (GTR for the earlier site in the Nilgiris is available on

INO's website.14)

For a mountain tunnel project, GTS is like the diagnostic study done before a major surgery to assess the survival chances. The US Free High Way Authority (FHWA) has evolved detailed guidelines for GTS and its website devotes 40 pages in two sections. "The cost of a complete geotechnical investigation program for a road tunnel project is typically about 3% to 5% of construction cost".15 INO study involved 5 field-days, while FHWA says that "the high cost, lengthy duration, limited access, and limited coverage of field investigations may demand that investigations be carried out in several phases to obtain the information necessary at each stage of the project in a more cost-efficient manner". The endpoints in a GTS can be broadly classified into two - (i) the prospects and problems of making the tunnel and (ii) the immediate, short term and long term impacts on the eco-system. The prospects and problems of tunnelling was the only objective of the GTS for INO, conducted by R Srinivasan of the GSI, Chennai. There is no mention about the impact on rivers, aquifer or reservoirs anywhere in the report. The geologist spent five days in the site in the months of March, April and October 2010. A site within the village grazing land was chosen for the portal, after rejecting two others in the private and forest lands. As per the order of the geologist, the Tamil Nadu Electricity Board drilled four samples, all around the chosen portal.

2.2.1 The Quality of data - excerpts from GTR

(a) "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*".

(b) "The rock outcrops at the eastern side of lower slopes were only examined and the observations are extrapolated to higher reaches."

(c) Quality of the bore-hole samples:

(i) "the cores were not arranged run-wise"

(ii) "no depth marking was done for each run, and only a cumulative depth for certain runs given"

(iii) "many samples did not have arrow marking indicating the direction of depth"

(iv) "driller's log sheet doesn't indicate water loss or water colour details."

(d) "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 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*."

(e) "This has resulted in the *approximate fixin*g of weathered rock and fresh rock levels".

2. 2. 2 Observations of the Geologist

(a) "The profuse intrusion of granite with closely spaced sub-horizontal joints probably along the margin of Suruliyar -Kambam shear zone is the rock characterisation in the portal area of access tunnel alignment."

(b) "The regional geological map shows a shear zone trending NNE-SSW and traversing access tunnel in middle reaches."

(c) "The only concern would the >1000 m of rock cover which would create stress related problems like rock bursts".

(d) "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 and there is a fall in the rock level to a depth of 27.41 m within 45 m distance"

(e) "Second generation geological maps prepared by GSI shows the presence of faults. In view of these observations, it is prudent that seismic coefficients for Magnitude 5 earthquakes is provided while designing the detector in the lab cavern".

2. 2. 3 Our comments

(a) Land above the caverns not studied

The geologist did not visit the land above the caverns, under which two-third of the blasts will be done. The place is reachable by road via village Shantanpara in Kerala.

(b) Low quality drill data

The major component of the study is analysis and characterisation of the drilled samples, the other components being visual observations and literature survey. The drilling was not done professionally and two subsequent drilling ordered was not done as they could not obtain the permission from the forest department! As the author himself says, the main part of the geo-technical study is an approximation.

(c) Underplaying the shear zone

In plate No-5, (page 20), both the shear zone and the tunnel are shown as single lines and they look like two roads intersecting each other in an acute angle. In fact, the caverns and the tunnel are located in the middle of the shear zone which is 10 km wide (see discussion and map below).

(d) Rock-bursts and their unpredictable effects

Citing the experience of tunnelling under a rock cover of 500 m for Pykara hydro-electric project (PUSHEP) in the Nilgiris, Srinivasan observes that "similar geological setting is expected at INO cavern also and *the only concern would the >1000 m of rock cover which would create stress related problems like rock bursts*." Incidentally, about 80% of the blasting will be done at depth >1000 m.

The significant findings of the GTS, viz., the seismicity of the region, the Suruli shear zone and the warnings of rock-bursts during 80% of the blasts are independent of the low quality borehole data. We will examine the implication of these issues.

2.2.4. The Ethical and legal Implications of Seismicity

According to the Bureau of Indian Standards, the site is in seismic zone 3[16] while the EIA for INO has an unreferenced statement that "the project location is *reported to be* situated in Seismic Zone 2"[17]. INO's FAQ (English) has a question "what happens when there is an earthquake or rock burst"[18], now a dead link as the answer, ('the site is in zone 2') has been removed in March 2013. The FAQ in Malayalam says that a "cave is the safest place during an earth-quake".[19] An INO official, also a co-author in Acharya et al, told the students of physics at the Cochin University for Science and Technology (CUSAT) on October 19, 2012 that "the INO site is in seismic zone 2, the lowest in India, and hence there is no room for any concern regarding tremors."[20] Acharya et al rightly point out that "geological characterisation are important not only for the safety of the environment around, but also for the safety of scientists working in the underground laboratory." Besides the ethical issue related to sending the young people to hazardous places without their informed consent, the legal issues will surface if an unthinkable event occurs. The earthquake, will affect only few people, that too only if the caves are completed. Blasting the shear zone can have other serious impacts.

3. Hydro-geology of the Site

3.1. The Suruli Shear Zone

Idukki-Theni districts are part of the Madurai block of the southern granulate terrain (SGT) in South India. V. Srinivasan and P. Rajeshdurai in their paper[21] based on satellite imageries and field checks say that "the Suruli ductile Shear Zone (SSZ) extends from west of Kadaiyanallur in the south to Ganguvarpatti in the north covering a length of 150 km." Its width is 200 m in the south and 10 km in the North and INO, with a total length of 2.1 km will be inside the SSZ. They saw "veins with perfectly developed calcite crystals" in several places, "crystalline limestone was being quarried" at two places and they inferred "a limestone deposit in Tiruvengadam synform". "There is no exposure of calc-granulite and these calcite crystal rich veins are mostly aligned along the gneissosity in host charnockite. The solution rich with calcium carbonate may have percolated downwards into the gneissosity, cracks and crevices of the underlying charnockite." The intensity of deformation increases from south to north along this shear zone. "In the northern end, between Vaigai River and

Ganguvarpatti, there are many exposures of mylonite (a fine-grained, compact rock produced by dynamic recrystallization of the constituent minerals resulting in a reduction of the grain size of the rock[22]) that were not observed in the southern end. At many places it is observed that the differentiated layering (gneissosity) in charnockite is parallel to the layering of the associated quartzo-feldspathic gneiss, (a major rock type from regional metamorphism[23]) granite gneiss and khondalite and this pervasive and penetrative gneissosity is also parallel to the lithological contacts."

3.2. 'A huge sheet of monolithic rock hill' in a sheer zone

The paper on the Suruli Shear Zone was published in April 2010 and GTR was finalized in November 2010. On 18 October 2010, R Ramachandran wrote that the scientists "finally chose a *huge sheet of monolithic rock hill* near Pudukkottai village for the project".24 The implication is that the scientists studied the site with ultra-sonograms, toposheets and satellite imageries. Even in fault-free areas, it is difficult to find a large block of crack-free hard rock as the Swedes learnt during their efforts to locate a granite block for a radioactive-waste repository.25 Cracks and crevices are important from the physics aspect of the neutrino detector also, besides the hydro-geology.

3. 3 Prior Studies on water resources and landslide

If calcium carbonate percolated down, there may be karsts and also confined or unconfined aquifers underneath. According to the map in Srinivasan and Rajeshdurai, the Vaigai, the Kakki and the Periyar reservoirs and the Suruli river are inside the sheer zone. SSZ may also have invisible links with the rivers and the aquifers. Brief summaries of a few recent path-breaking studies on the tectonics, hydrology and landslides around the proposed site are given below.

Magesh et al[26] conducted a study focusing on the identification of groundwater potential zones in Theni district, integrating remote sensing with GIS. They prepared various thematic layers, such as lithology, drainage density, lineament density, rainfall, slope, soil, and land-use with assigned weightage in a spatial domain.

Ramasamy et al[27] used GIS based visualization of groundwater levels of 1985, 1990 and 1995 for a part of the Western ghat hill-plain region of Tamil Nadu and interpreted features like ridges, valleys, domes and basins. The study yielded newer information on geosystem processes and their interface dynamics with hydrosystems. In a review article on the remote sensing and active tectonics, Ramasamy discusses the "ongoing land subsidence in addition to sinistral movements along the two sub parallel lineaments, from Pondicherry in the north-east to the Kambam valley in the south west along with youthful stage floodplain in the Suruliyar river" .[28] There is a also a serious risk of landslide as revealed in a landslide vulnerability mapping done by Kannan et al using both satellite and field data in Bodi-Bodimettu ghat section of the National Highway, less than 20 km from the proposed INO site.[29]

3.4 Seismicity and Safe Tunnelling technology

Acharya et al say that "tunnelling is a routine activity in mountains (even in the Himalayas which is the most seismically active region in India), under the rivers and seas, and even under mega cities for metro rail transportation" and "it is hard to believe that such an activity can cause major or even minor earthquakes." The US FHWA says that "rocks with weak planes such as shear zones would clearly indicate a potentially significant seismic risk to a tunnel"[30] while Jorge et al say that "some of the most disastrous experiences in tunnelling have been the result of interception of large flows of water from highly fractured water-saturated rocks."[31]

3.4.1 Indian Experiences in Tunnelling and Aquifer - The Case of Rohtang

India has not been a major player in tunnelling. Out of 57 km of rail tunnel in India, 63% was commissioned in 1997 (all on Konkan Railways), 33% between 2005-12 and only 4% in 1982.[32] Among 50 rail tunnels longer than 13 km in the world commissioned before 2012, there is none from India.[33] For the few smaller tunnels constructed in India, no comparative studies of pre- and post tunnelling flows have been done. A tunnel from a reservoir is on a negative gradient and if it ruptures an aquifer, the water will flow into the generating station or the distribution network. This will be a positive effect from the perspective of the dam builder, though this gain of course will be matched with a loss elsewhere. Tunnelling in the 'high value regions' like cities are done after systematic studies such as the one conducted by the Indian Institute of Science[34] for the Bangalore metro. In mountain regions, the large overburden, logistics, low population density and the absence of an environmental movement prompt the builders to forgo safety assessment and face the risks as the recent experience in the Himalayas shows.

The construction of 8.8 km long Rohtang Tunnel (3,100 m MSL) in Himachal Pradesh, under the Rohtang Pass (3,978 m MSL) in the Pir Panjal range of the Himalayas on the Leh-Manali Highway began in June 2010. Rohtang, one of the longest road tunnels in India, on a route vital for military supplies, will reduce the distance between Manali and Keylong by 60 km. The Indian Army is in charge of the Austrian technology based construction.[35] Studies were reportedly conducted by agencies like the National Hydro Power Corporation, Konkan Railways, GSI and Snow and Avalanche Study Establishment[36], none available in the public domain. On completion of 2 km, the builders encountered a fault line and an underground spring. On 5 June 2012, a "rivulet gushed out",[37] with an ingress of 3 million litres of water per day.[38] This has slowed the progress of excavation from 5 metre to just 0.5 metre a day and requires 24x7 de-watering".[39] Acharya et al claim that "the technology has improved tremendously in the last few decades". True, but there are a few problems like safe tunnelling in shear zones, disposal of high level radioactive waste and cure for genetic diseases like Down Syndrome reserved for our F-3 generation of scientists and inventors!

3. 5 Charnockyte aquifer, not our invention

The nomenclature charnokite aquifer is used in the Central Ground-water Board's aquifer mapping reports for Kerala[40] and Tamil Nadu[41], authored by 33 earth scientists.' By the way, about a third of the ground-water in Tamil Nadu is inside the so-called charnockite aquifer and there is a small one in Chennai also. Scholar.google returned 667 entries for hard-rock aquifer, 304 for granite aquifers and for 6 for charnockite aquifer. There are 52 entries for granite aquifer in the US Geological Services document server also. While summing up the LNGS experience, Rajasekharan missed an important link, the sequence being rupturing an underground spring and depletion of aquifer which might have caused the earth-quake. This is not uncommon, its physics is the same as that of reservoir-triggered seismicity. We were just quoting the Italian geologists who studied the Gran Sasso events and our main concern is aquifer impact of tunnelling in an earth-quake prone area, which is an established fact.

3. 6 The Long term and chronic impacts on hard rock aquifer.

Balachandran believes that hard rock aquifers are not prone to tunnelling impacts. In 2010, Vincenzi et.al wrote that "in hard rock aquifers it is extremely difficult to forecast either major inflows occurrence along the tunnel or the associated effects on surface waters and groundwater, due to the highly heterogeneous distribution of hydraulic conductivity (K) and the consequent strong dependence of major inflows on the interception of localized geological features.42 Besides the abrupt impact, chronic depletion and eventual drying of hard-rock aquifers are possible. The US Armed Forces Special Weapons Command, (AFSWC) constructed after the World War II in Manzano Mountains which provide 70% of the water recharge for the Estancia Basin, is an example. Though proposed as a command post for President Dwight Eisenhower, he did not stay there, but part of the US nuclear arsenal was there till 1990. According to one report, "over the last 50 years, well records indicate the depth of the water table declined by several hundred feet, with total depletion of the aquifer within as little as 40 years affecting tens of thousand of land owners within an area the size of some small eastern states.”43

3.7 More on anthropogenic earth-quakes

Balachandran has introduced refreshingly new ideas about induced earth-quakes, which will be keenly debated by the earth-science community. Though geology is a matured science, the young scientists keep on springing more surprises, such as this one by van der Elst et al[44] who report that mega earthquakes in Chile (2010), Japan (2011) and Sumatra (2012) triggered earthquakes in Oklahoma, Texas and Colorado in USA. They say that "areas with suspected anthropogenic earthquakes are also more susceptible to earthquake-triggering from natural transient stresses generated by the seismic waves of large *remote* earthquakes" and they have named this 'triggered-induced earthquake'. Earlier, Keranen et.al. had linked the induced 5.7 M earth-quake near Prague, Oklahoma to waste-water injection from oil production, with "decades-long lags between the injection and the onset of induced earthquakes" which "modifies our common criteria for fluid-induced events."[45] Again,"the amount of waste water injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock. There's something important about getting unexpectedly large earthquakes out of small systems that we have discovered here".[46] Considering its seriousness the US NAS called for further research to "understand, limit and respond" to induced seismic events.[47]

4. Discussion

4.1 Physics requirement of the neutrino detector

Neutrino detectors are placed underground or under water with a minimum overburden of 3000 meters of water equivalent (mwe) to filter out the charged sub-atomic particles, known as cosmic radiation, originating from the stars and other unknown exotic places. Since the particle size is femtometer (10^{-15} m) even small, invisible cracks should be avoided in all sides of the detector. Choosing a site in the middle of a highly degraded shear zone, without even a field visit to the epicentre raises doubts regarding the real purpose of the mission.

4.2 Free Science from politics

In 2004, Boominathan revealed that “confirmatory geological and geo-technical investigations carried out after excavation of strata to the founding level at various sites for nuclear facilities show the presence of weaker zones which were not identified in the original investigation." His advice that "ecological and geotechnical investigations shall be well planned and executed by *reputed agencies at the beginning stage of the investigation"*[48] seems to have fallen in deaf ears. (Italics ours) Reputation of the agencies is important, more important is the contract. SACON and GSI who did the EIA and GTS for INO are reputed agencies. In this case, they were asked to lend their sciences for rationalizing a political decision. The EIA system in India has become corrupt, because the promoters, most of whom would be the future polluters, pay for the EIA and choose the scientists.

4. 3 Holton's self-fulfilling prophecy?

Acharya et al's unconditional faith in technology reminds us of the physicist-philosopher, Gerald Holton's prophetic words during a lecture in Kashmir, in 1970 that "the 19th-century faith that science will show the way to the solution of all problems and lead us soon to Utopia was a tragically naive illusion." Was Holton's idea that "science and its technological offspring must come under the control of an anthropocentric ethic if human is to survive"49 a self-fulfilling prophecy? Four decades down the line, eminent scientists and philosophers from the Oxford[50] and the Cambridge[51] universities are discussing the "global catastrophic risk" (GCR) and "existential risk" (ER) from biotechnology, geo-engineering, nanotechnology and artificial intelligence. As Martin Rees observes, "we're entering an era when a few individuals could, via error or terror, trigger societal breakdown."[52]

In his essay on the anthropogenic earthquakes, Elseworth reminds us that "ignorance of the things that we understand we should know but do not, leaves us vulnerable to unintended consequences of our actions".[1] When the ecological footprint of their own projects were brought to light, the proponents could have studied the GTS, enquired as to why it had to be classified as confidential, looked at the recent experiences of such projects and the regulatory regime and practices now in vogue in other nations. This is the tragedy of modern science and Peter Singer's observation about the latest military applications is equally relevant in this debate also. Singer says that "our sophisticated inventions and our crude grasp of the consequences continues to widen.

Academic journals of each field focus inward, professional conferences are attended only by the like-minded, and those who attempt to straddle disciplines or engage the public are viewed as less serious”.[53]

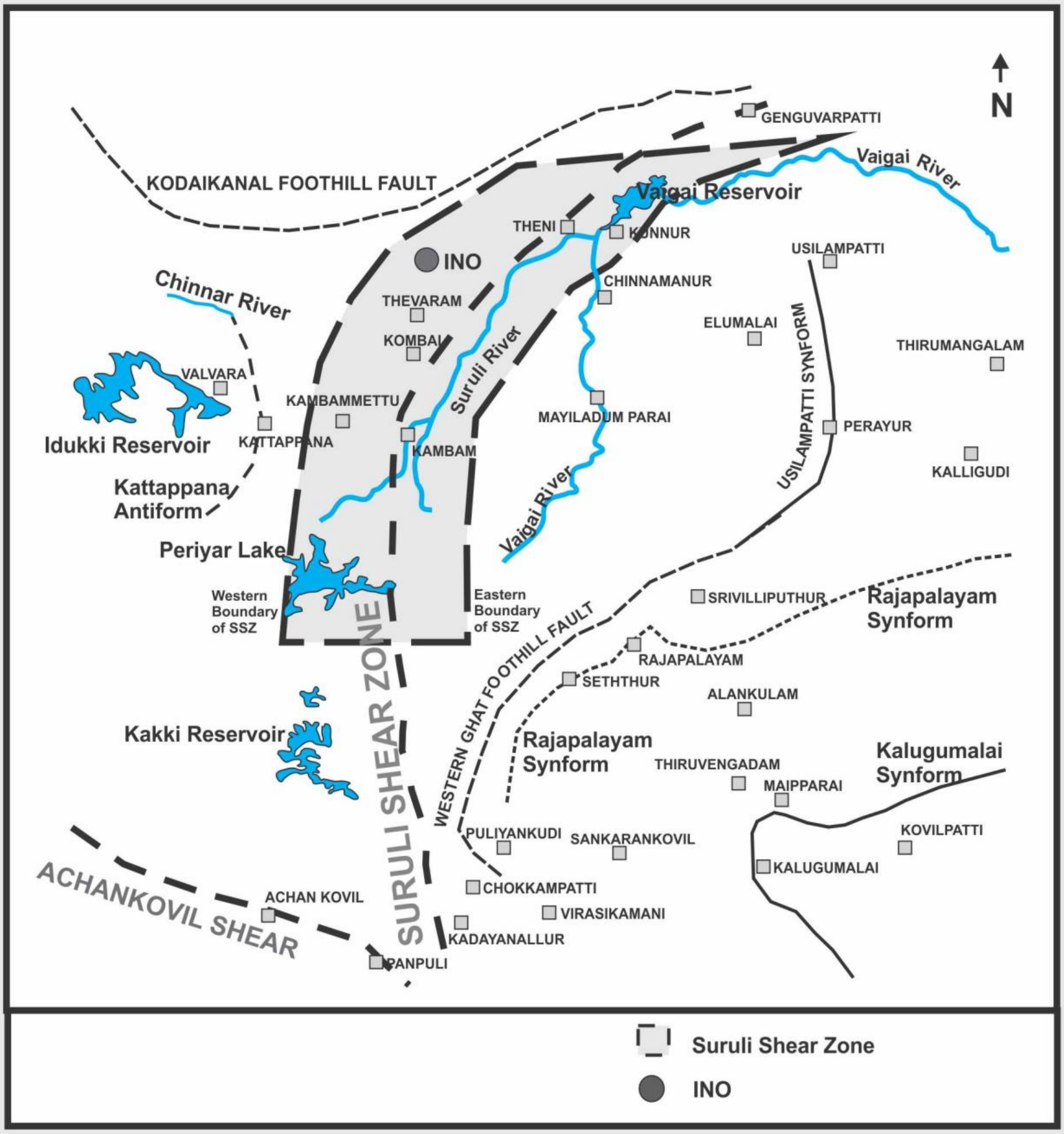
4. 4 The False consensus and the Crisis in modern science

What we are discussing here is a simple geological problem and one may wonder why the earth scientists are not speaking out? In connection with the Sethusamudram Shipping Canal Project (SSCP)54, Rajendran wondered as to why the scientists are leaving "all these important decisions to some influential bureaucrats and politicians who are clever enough to hide under some technicalities and poorly whetted reports?" and on the role of "the national academies and professional bodies of Indian scientists?"[55] INO is a DAE project, and is also part of the US-India Nuclear Deal.[56] In a letter published in this journal, Agoramoorthy and Chakraborty had asked "when academicians express their scientific views with the support of data to portray the potential dangers of earth-quakes to nuclear power plant sites, does it warrant ill-treatment and deportation?"57 The ill-treated scientist, Roger Bilham had written on the earthquake hazards of the proposed French nuclear park at Jaitapur in Maharashtra.[58,59] A report in Nature quotes the observation of the Washington DC based Association for Tropical Biology and Conservation that the EIA for the earlier site in the Nilgiris was also seriously flawed[.60]. INO used reports based on falsified or low quality data for obtaining the government's clearance and funding. This is an affront to the environmental governance and the rule of law. Forest encroacher and small time quarry owners do indulge in bigger violations, but a science institution formed by collaboration of over a hundred finest minds and funded by a Department headed by the Prime Minister of the nation should act as a role model. The first national mega science project, a “perfect launching pad for attracting fresh blood into basic sciences in India"'61 should have been planned more meticulously, with transparency, care and compassion.

5. Conclusion in the womb of a whirling worm?

The main reasons for selecting the proposed site in Bodi West Hills in Theni district are the charnockite rock and the seismic stability. These are not fulfilled as the rock type is not charnockite and the place has high earthquake risk. The cracks and faults in the rocks of the highly degraded shear zone will increase the noise from cosmic radiation in the lab and make any detection of the weakly interacting neutrinos impossible. Unlike a road or rail tunnel or mine, there is no compelling reason for INO to be located in its proposed site. Major neutrino observatories and underground laboratories in the world are located in used mines, ocean beds, lake or ice sheet. LNGS, the only one, located on a mountain range with a horizontal access has been a perfect ecological disaster. INO's only reason to hang on to the present site is the government's sanction obtained without undertaking a proper, scientific risk analysis and bypassing the established procedures of public consultations. Writing on the neo-tectonism in SGT, Ramasamy used the metaphor of a whirling worm. INO is planning to place the world's biggest underground science laboratory, -that perfect launching pad for attracting fresh blood into basic sciences in India-, its hundred odd young particle physicists and a 100 KT magnet and assorted machines in the womb of that whirling worm.

Location of INO in Suruli Shear Zone



Map based on: Map in V Srinivasan,P Rajeshdurai, "The Suruli shear zone and regional scale folding pattern in Madurai block of Southern Granulite Terrain, south India", *J. Earth Syst. Sci.* 119, No. 2, April 2010, pp. 149

Reference

1 Ellsworth.,W.L., 2013, Injection-Induced Earthquakes, 12 July 2013:Vol. 341 no. 6142. DOI: 10.1126/science.1225942

2 Acharya, B. S. et al, 2013, India-based Neutrino Observatory, Correspondence, Current Science, Vol. 104, No. 7, 10 April 2013 811. http://www.currentscience.ac.in/Volumes/104/07/0811.pdf

3 Balachandran. V., 2013, Mountain tunnelling, aquifer and tectonics – a case study of Gran Sasso and its implications for the India-based Neutrino Observatory by V. T. Padmanabhan and Joseph Makkolil – a critique, CURRENT SCIENCE, VOL. 104, NO. 11, 10 JUNE 2013 pp 1479-81http://www.currentscience.ac.in/Volumes/104/11/1479.pdf

4 Padmanabhan. V. T and Makkolil, J. 2013, Mountain tunnelling, aquifer and tectonics – a case study of Gran Sasso and its implications for the India-based Neutrino Observatory, CURRENT SCIENCE, VOL. 104, NO. 4, 25 FEBRUARY 2013 414. http://www.currentscience.ac.in/Volumes/104/04/0414.pdf

5 Ramachandran, R., 2009, Ministry's 'no' to Neutrino Observatory project in Nilgiris, http://www.hindu.com/2009/11/21/stories/2009112154952000.htm

6 Jayaraman, K. S., 2009, Indian neutrino lab site rejected, Nature, 462, p 397 http://www.ino.tifr.res.in/ino/news/22%29Nature-Nov-09.pdf

7 Anonynous, 2009, Draft Notes September 2009 INO/IMSc/2009/06 India-based Neutrino Observatory project Proposed locations in Kambam region Theni District, Tamilnadu.

8 http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/scientists-clear-doubts-on-neutrino-observatory/article506958.ece

9 Ramachandran, R.,2010, http://www.thehindu.com/news/national/tamil-nadu/neutrino-project-approved-at-bodi-west-hills-in-theni/article836333.ece

10 Srinivasan, R.,2010., Preliminary Geotechnical Report On Pottipuram Site (A 1589) For Locating Underground Laboratory Of India Based Neutrino Observatory, Theni District, Tamil Nadu.

11 Mallady, S.V., The Hindu, January 4, 2012 http://www.thehindu.com/todays-paper/state-government-hands-over-land-for-rs1260crore-neutrino-observatory/article2773468.ece

12 Ramachandran, R., The Hindu, October 8, 2012 http://www.thehindu.com/opinion/lead/a-controversy-we-can-do-without/article3975090.ecN.S

13 http://www.thehindu.com/news/cities/Thiruvananthapuram/ino-to-study-atmospheric-neutrinos/article4004991.ece

14 Balachandran, V., Thanavelu, C., and Srinivasan, R. 2009 Appendix C: Geotechnical forecast along the preferred alignment, India based Neutrino Observatory project. http://www.imsc.res.in/~ino/OpenReports/singara.pdf

15 http://www.fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/03.cfm

16 http://ndma.gov.in/ndma/eqmeasurement.html

17 Azeez, P. A., Nikhil Raj, P. P. and Murugesan, M. 2010, Rapid EIA of the India-Based Neutrino Observatory Project, Bodi West Hills, Theni, Tamil Nadu. Sálim Ali Centre for Ornithology & Natural History, page 55. www.ino.tifr.res.in/ino/reports/REIA-Final_doc.pdf

18 http://www.ino.tifr.res.in/ino/faq.php#earthquake

19 http://www.ino.tifr.res.in/ino//docs/inofaq_mal.pdf

20 The Hindu, Kochi, October 19, 2012 http://www.thehindu.com/news/cities/Kochi/neutrino-project-work-not-a- threat-to- mullaperiyar-dam/article4012326.ece

21 Srinivasan, V., Rajeshdurai, P. 2010 The Suruli shear zone and regional scale folding pattern in Madurai block of Southern Granulite Terrain, south India, J Earth System Sc, 119, Issue 2, pp.147-16. http://ns1.ias.ac.in/jess/apr2010/147.pdf

22 en.wikipedia.org/wiki/Mylonite

23 geology.about.com/od/rocks/ig/metrockindex/rocpicgneiss.htm

24 Ramachandran,R., The Hindu, October 18, 2010. http://www.thehindu.com/news/national/tamil-nadu/neutrino-project-approved-at-bodi-west-hills-in-theni/article836333.ece

25 Feiveson, H., Mian, Z., Ramana, M.V., and von Hippel, F. (ed) 2011, International Panel on Fissile Materials,Managing Spent Fuel from Nuclear Power Reactors, Experience and Lessons from Around the World, page 17 http://www.princeton.edu/sgs/publications/ipfm/Managing-Spent-Fuel-Sept-2011.pdf

26

Magesh, N.S., Chandrasekar,N., Soundranayagam, J.P. 2012, Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. http://www.hidro.ufcg.edu.br/twiki/pub/GeotecnologiaAplicada0/CASemestreAtual/Mageshetal2012.pdf

27 Ramasamy, S.M., Kumanan, C.J, Mahalingam,S., and Nagappan,N. 2007. GIS based visualization of groundwater level and its significance. J of Geomatics, Vol.1, No.1, pp. 17-22, I http://www.ruraluniv.ac.in/71_3D_WATER_LEVEL.pdf

28 Ramasamy, S.M. 2006 Remote sensing and active tectonics of South India International Journal of Remote Sensing Vol. 27, No. 20, 20 October 2006, 4397–4431 http://www.scribd.com/doc/7182207/Active-Tectonics-South-India

29 M. Kannan,M., Saranathan,E., and Anabalaga, R. 2012 Landslide vulnerability mapping using frequency ratio model: a geospatial approach in Bodi-Bodimettu Ghat section, Theni district, Tamil Nadu, India Arabian Journal of Geosciences May 2012 DOI 10.1007/s12517-012-0587-5

30 http://www.fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/13.cfm

31 Molinero, J., Javier, S. and Juanes. R., "Numerical modeling of the transient hydrogeological response produced by tunnel construction in fractured bedrocks." Engineering Geology 64.4 (2002): 369-386.ftp://ftp.unine.ch/Kiraly/Papers/Molinero02.pdf

32 http://www.lotsberg.net/data/india/list.html

33 http://en.wikipedia.org/wiki/List_of_long_tunnels_by_type

34 Sekhar, M. ,Mohankumar. M.S., 2009. Geo-Hydrological Studies Along The Metro Rail Alignment In Bangalore, Department of Civil Engineering, Indian Institute Of Science. http://bmrc.co.in/pdf/news/IISc-Report.pdf

35 http://en.wikipedia.org/wiki/Rohtang_Tunnel.htm

36 Chauhan P., 2003, Rohtang tunnel to affect area ecology, warn experts, Tribune News Service, 11 August 2003

37 www.dailypioneer.com. 5 June 2012.

38 http://articles.timesofindia.indiatimes.com/2012-11-19/india/35204208_1_rohtang-tunnel-longest- tunnel-ingress

39 http://www.tribuneindia.com/2012/20120709/main6.htm

40 Dhiman, S.C. and Nandakumaran, P., Aquifer Systems of Kerala, Government of India, Central Groundwater Board, .2012 http://cgwb.gov.in/AQM/Kerala.pdf

41 Dhiman, S.C., Thambi, D.S.C., Dhayamalar, D., Senthilkumar, M., Arumugam, R., Piramanayagam, S., Ramesh Kumar, N., Gnanasundar, D., Aquifer systems of Tamil Nadu and Puducherry, Central Groundwater Board, Government of India, . 2012. http://cgwb.gov.in/AQM/Tamil%20Nadu.pdf

42 Vincenzi, V., Piccinini, L., Gargini, A. and Sapign, M. 2010, Parametric and numerical modelling tools to forecast hydrogeological impacts of a tunnel, , AQUA mundi (2010) - Am02017: 135 –154. DOI 10.4409/Am-021-10-0017

43 http://www.globalsecurity.org/wmd/facility/manzano.htm

44 van der Elst, N. J., Savage, H. M., Keranen, K. M., & Abers, G. A. (2013). Enhanced remote earthquake triggering at fluid-injection sites in the midwestern United States. Science, 341(6142), 164-167.

45 Keranen, K.M., Savage. H.M., Abers. G.A. and Cochran. E.S. (2013) Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence, http://geology.gsapubs.org/content/early/2013/03/26/G34045.1.full.pdf+html. doi:

10.1130/G34045.1

46 http://phys.org/news/2013-03-wastewater-spurred-biggest-earthquake.html#nwlt

47 http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/Induced-Seismicity-Report-Brief-Final.pdf

48 Boominathan, A. 2004 Geotechnics And Earthquake Hazards site characterization for nuclear structures and power plants, Current Science, Vol. 87, NO. 10. www.iisc.ernet.in/currsci/nov252004/1388.pdf

49 Holton, G.,The relevance of physics, Phys. Today 23(11), 40 (1970); http://dx.doi.org/10.1063/1.3021828

50 http://www.fhi.ox.ac.uk/research

51 http://cser.org/

52 Rees, M., Denial of Catastrophic Risks, Editorial. Science, 8 March 2013: Vol. 339 no. 6124 p. 1123 DOI: 10.1126/science.1236756 http://www.sciencemag.org/content/339/6124/1123.ful

53 Singer. P. W., A world of killer apps . Leaders are ill-prepared for the ethical complications of new 'killer applications', Nature, 477: 399, 2011. www.nature.com/nature/journal/v477/n7365/abs/477399a.html

54 Ramesh R. Sethusamudram shipping canal project, CURRENT SCIENCE, VOL. 88, NO. 4, 25 FEBRUARY 2005 http://www.iisc.ernet.in/~currsci/feb252005/536.pdf

55 Rajendran, C. P , 2005, Sethusamudram shipping canal project and the eternal silence of the Indian earth scientists, Current Science, VOL. 89, NO. 2, 25 JULY 2005. http://www.iisc.ernet.in/currsci/jul252005/246.pdf

56 Collaboration between Indian and US laboratories on Accelerator technologies ... sbhepnt.physics.sunysb.edu/~grannis/DOE/foreign Collaboration/ between Indian and US laboratories on Accelerator...

57 Agoramoorthy. G. and Chakraborty,C., 2013, Is India open to scientific criticism?, Current Science, VOL. 104, NO. 4, 25 February 2013. http://www.currentscience.ac.in/Volumes/104/04/0406.pdf

58 Bilham, R.; Gaur, V. K. 2011, Historical and future seismicity near Jaitapur, India, Current Science, 25 November 2011, 101 (10) http://www.currentscience.ac.in/Volumes/101/10/1275.pdf

59 Gaur, V. K. ; Bilham, R. 2012, Discussion of seismicity near Jaitapur , Scientific Correspondence, 10 December 2012, 103 (11) http://www.currentscience.ac.in/Volumes/103/11/1273.pdf

60 Jairaman K. S., 2009. Elephant and the Neutrino, Nature, 461, 24 September 2009, p 459 www.nature.com/news/2009/091124/full/462397b.html

61 Kakodkar. A. quoted in Bagla, P., 2009, Indian neutrino detector hits snag on environmental concerns. Science Vol 323 9 January 2009. http://www.sciencemag.org/content/323/5911/197.summary. DOI:10.1126/science.323.5911.197