

GEOELECTRICAL INVESTIGATIONS ON COASTAL AQUIFERS TO ASSESS THE SALINE WATER INTRUSION IN NGHI SON, THANH HOA

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ABSTRACT: This paper presents the results of geoelectrical investigations for delineation of the aquifers and determination the hydrogeological situation of the water bearing in Nghi Son economic zone. Following the geophysical investigations and the stratification of geological formation, the boundary between fresh and saline water is determined in study area. The geoelectrical measurements indicate that the saline water intrusion within the Pleistocene aquifer occurs along the coastline of the Northeast part of Nghi Son economic zone. The values of formation resistivity below 20 Ωm imply that the water bearing is brackish or saline water. The geophysical results are corresponding to borehole nearby profiles. The geoelectrical methods have proved to be appropriate tools to investigate 2D geological structure in the coastal areas that have low resistivity of subsurface.

Keywords: Geoelectrical investigations, apparent resistivity, saline water intrusion.

INTRODUCTION

The economic zone, Nghi Son - Thanh Hoa, is an important industry park in North Centre of Vietnam. It stretches over natural area of twelve communes belonging to Tinh Gia district, Thanh Hoa province. Requiring a high amount of water demand, Nghi Son economic zone is facing the lack of fresh water for living and production. Almost all the water supply for Nghi Son economic zone comes from surface water resources such as rain fall, rivers and lakes. The ground water only exists with a narrow area for both Holocene and Pleistocene aquifers. The ground water is only extracted in family water wells. The unprompted extraction of ground water on small scale may pollute the aquifers due to the saline water intrusion [1, 2].

Saltwater intrusion is the movement of

saline water into freshwater aquifers. The detection and quantification of this phenomenon is the target of geoelectrical methods in coastal environment. Geoelectrical methods have proved to be efficient tools for geoenvironmental investigations on saltwater intrusion in coastal areas because the salt content of water dominates the electrical conductivity of the sediments [3, 4]. Based on geoelectrical investigations, the structure of aquifers and the transition zone between fresh/saline water can be delineated. Note that geoelectrical measurements do not directly detect the saline water but they can measure the characteristic increase of formation conductivity, which is caused by the saltwater intrusion phenomenon.

The main water bearing formations in Nghi Son economic zone are Holocene and

Pleistocene aquifers. Following previous researches, the Holocene is a poor water bearing formation while the high potential Pleistocene aquifer contains both fresh and saline water. To delineating the geological structure and to assess the hydrogeophysical situation of the aquifers, the geoelectrical investigations are proposed. The inversed modelling of geoelectrical investigations determined the distribution of aquifers. The value of formation resistivity, referred from geoelectrical measurements, indicated the hydrogeological situation of the aquifers. The

low value of water bearing formation shows that the porous fluid has a high concentration of salt [5].

The study area covers natural area of twelve communes in the Nghi Son economic zone. Fifty stations of Vertical Electrical Sounding (VES) and nine profiles of 2D Resistivity Imaging (RI) were carried out to determine the geological structure and estimate the hydrogeological situation of the aquifers. Fig. 1 shows the study area and the positions of geoelectrical surveys in Nghi Son.

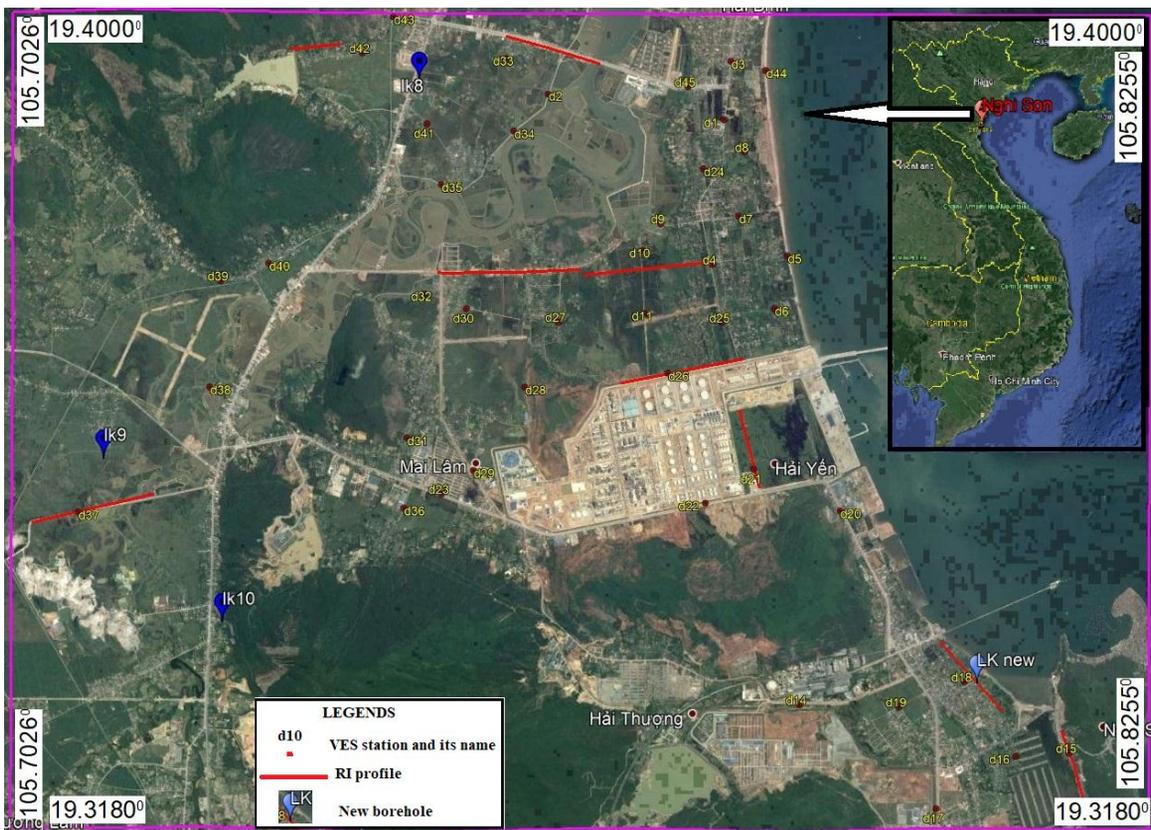


Fig. 1. The position of geoelectrical investigation in the study area

GEOLOGICAL AND HYDROGEOLOGICAL SITUATION

In Nghi Son area, many water bearing formations can be found in the shallow subsurface, but some of them contain brackish groundwater or the water quantity is not abundant. The most significant formation is the

Pleistocene aquifer (qp) which is distributed all over the area of investigation and it is not exposed on the surface. The lithology consists mainly of quartz sand to gravel. The aquifer covers directly the bed rock named Dong Trau formation (T_2adt_1). The depth of this aquifer is about 30 - 60 m in the coastal line. The thickness of the aquifer increases from inland

to the sea, reaching 30 - 40 m in the coastal areas. An aquifuge containing river sediments (mQ_{III}^{2vp}) and sea-river sediment (amQ_{III}^{2vp}) consisting mainly of clay and clayey sand covers directly the Pleistocene aquifer. The Holocene aquifer is found above that aquifuge. It can be divided into the Lower Holocene (qh1) aquifer and Upper Holocene (qh2) aquifer. The Lower Holocene aquifer is a confined aquifer which consists of fine-grained sand and clayey sand sediments. The Upper Holocene is an unconfined aquifer consisting of sandy clay. The partition of Upper and Lower Holocene aquifers is not clear. Both Upper and Lower Holocene aquifers are poor water bearing formations and contain the poor quality water.

The sketch of hydrogeological map of Nghi Son area is shown in fig. 2. It indicates that the Pleistocene aquifer is the most potential water bearing formation at Nghi Son, Tinh Gia. However, following the previous researches, the fresh water is only found in a narrow area of the Western and Southern regions of the study area. Saline water intrudes in the North-East part of study area. That means that the boundary between fresh and saline groundwater in Pleistocene is located in the study area of Nghi Son economic zone. The geoelectrical investigation is aimed to determine the boundary between fresh and saline groundwater and estimate the hydrogeological situation of the shallow aquifers in the study area.

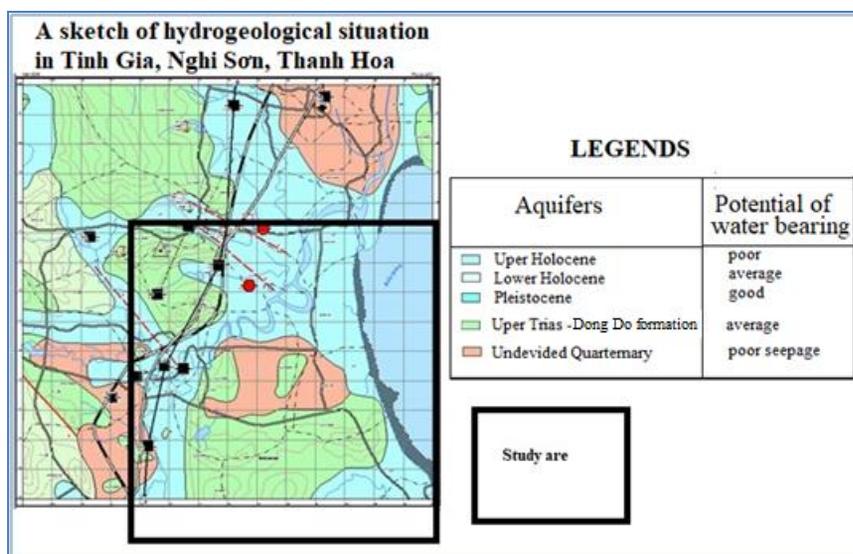


Fig. 2. A sketch of hydrogeological map of Nghi Son economic zone

GEOELECTRICAL MEASUREMENTS AND DATA INVERSION

To map the resistivity distribution of a vertical section, the Resistivity Imaging (RI) measurements using SuperSting R8/IP equipment (USA) with the electrode spacing of 10 m are used. The Schlumberger array is used and the croll long technique is applied for the long profile. Nine RI profiles have a total of more than ten kilometers of length (fig. 1). The current intensity ranges from 500 mA to

2000 mA. The measured data file is stored in format type of software Earth Imaging 2D. For Vertical Electric Sounding (VES), we use the Schlumberger configuration with AB/2 maximum reaching 400 m. Fifty VES stations were carried out in the study area. For each reading of VES measurement, the apparent resistivity of formation is written in paper sheet and sketch in semi log - log scale. The measured data is inverted by the software Earth Imaging 1D. The positions of VES stations and RI profiles are displayed on fig. 1. A new

borehole is performed at Hai Thuong commune to examine the geological structure and determine the hydrogeological situation in the study area.

RESULTS AND DISCUSSION

The geoelectrical soundings were carried out to determine the geological structure and the distribution of formation resistivity. Fifty VES stations are displayed in fig. 1. The measured data were inversed by 1D Earth Imaging software. The result of inversion is the modelling of geological structure with layers and resistivity of formation. Fig. 3 shows the inversed result of VES station number 18 (D18) and the stratification of closed bore hole at Hai Thuong commune. In the left side, the inversion of VES station shows a model of geological structure at measured position. The layered model can be divided into four layers which are equivalent to the geological formations at measured site. The Holocene aquifer, including Upper and Lower Holocene formations, is distributed from the surface to a depth of 25 m. The resistivity of Holocene

formation varies in range from 20 Ωm to 100 Ωm. An aquifuge is found from depth of 25 m to 55 m. This is Quaternary sediment, Vinh Phuc formation (Q_{III}²vp). Resistivity of Vinh Phuc formation is 29 Ωm for this VES station. The Pleistocene aquifer is determined at depth of 55 m to 75 m with resistivity of 46 Ωm. The resistivity value indicates that the Pleistocene aquifer contains fresh water [5, 6]. A new borehole was performed close to the VES station D18 (fig. 1). The stratification of borehole is displayed in the right side of fig. 3. The Pleistocene aquifer is found at depth of 60 m. The lithology of Pleistocene aquifer includes sand and gravel. A soil sample of Pleistocene aquifer was taken at depth of 68 m. The laboratory investigation shows a resistivity value of 70 Ωm for this soil sample. It indicates that the formation is bearing fresh water. The inversion result of VES D18 shows the equivalence to the stratification of closed borehole LK-1. The resistivity of formation (both VES result and LAB measure) shows a similar value. This can be inferred that the Pleistocene at this site contains fresh water.

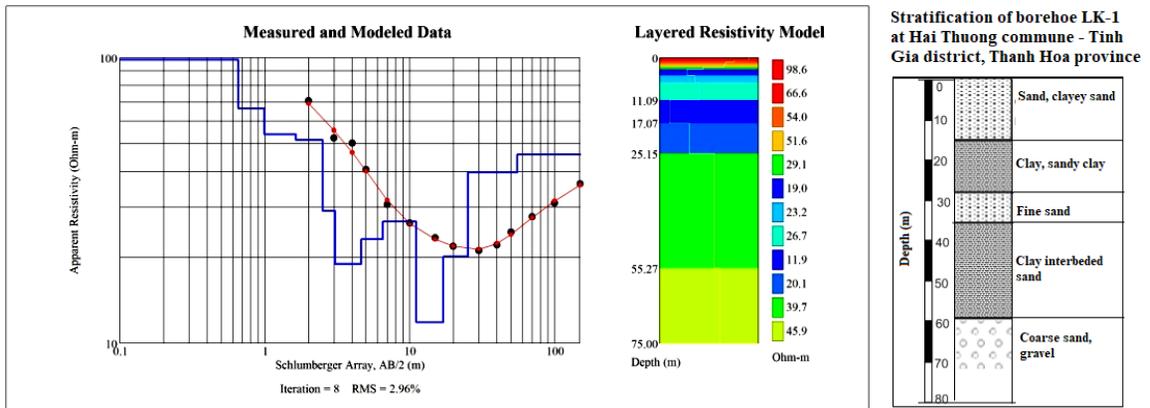


Fig. 3. The modelling of VES station D18 and the stratification of closed bore hole

Another VES station D3 shows a different result compared to the VES station D18. The inversion result of VES station D3 is shown in fig. 4. The inversed result shows that the Upper Holocene aquifer contains brackish water with the resistivity of formation of 31 Ωm (top layer in the model - fig. 4). The Holocene aquifer is distributed to the depth of 38.5 m. The Pleistocene aquifer is located between 62 m

and 99 m of depth. The resistivity of the Pleistocene layer is 18 Ωm. It indicates that the formation contains saline water.

Fifty VES stations are individually inversed in the same way. Finally, the spatial distribution and resistivity of aquifers and aquifuge are determined. For the VES surveys, the VES curves can be grouped into two types

of curve. The VES curves, which show a high value of resistivity for the Pleistocene formation, mean the Pleistocene formation containing fresh water. In the other area, the inversion of VES sounding shows a low value of the Pleistocene formation resistivity. The

VES measurements give resistivity of sediment corresponding to Holocene and Pleistocene formations. The inversed result can be used to delineate the geological structure and the hydrogeological situation at the position of VES station.

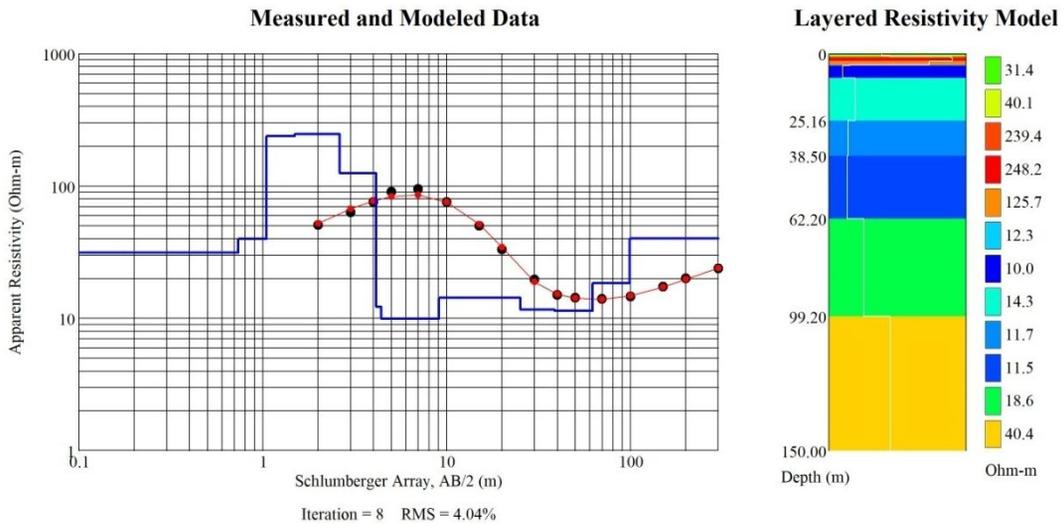


Fig. 4. The VES D3 curve and the layered model after data inversion of VES D3

The 1D VES measurements are only applied for the parallel layered model. The lateral change of resistivity is only monitored by 2D resistivity imaging surveys (Loke (1999)). In the study area, nine profiles of 2D Resistivity Imaging are carried out. Following the results of VES measurements, the Pleistocene formation contains brackish water in the Northeast part of study area. However, the boundary between fresh and saline groundwater is not determined. Therefore to locate the boundary between fresh and saline water zone in the Pleistocene aquifer, 2D measured profiles are designed perpendicularly to the boundary. The 2D resistivity investigations are performed using Schlumberger configuration with the electrode spacing of 10 m. The measured data is inversed by the Earth Imaging software which applies the finite element method to calculate the apparent resistivity of 2D resistivity modelling.

To determine the boundary between fresh and saline water in the Pleistocene aquifer, the 2D resistivity investigations are performed on 2

profiles perpendicular and one profile parallel to the coastline. The RI profile includes 2 or 3 separated sections which have the same direction. 2D inversion of measured data is performed individually following the RI sections.

Fig. 5 shows the inversion result of the three RI sections at Southeast part of the study area. The resistivity imaging profile is parallel to the coastline. The position of RI measured section is displayed on the right side. RI inversed sections are displayed using the same resistivity color scale. Look at the RI inversed sections, it is easy to recognize that there is a gradual change of resistivity distribution in the Pleistocene formation from the first to the second and to the third RI section. For the Pleistocene aquifer, the resistivity is about 10 Ω m at the top section, 20 Ω m at the middle section and 40 Ω m at the bottom section (fig. 5). It indicates that the groundwater changes from saline water to fresh water in the Pleistocene aquifer. That means the fresh/saline water boundary is located in the middle

between the first and the second sections of RI measurements. The resistivity of the Pleistocene formation varies in range from 10

to 50 Ωm along RI profile (three RI sections in fig. 5).

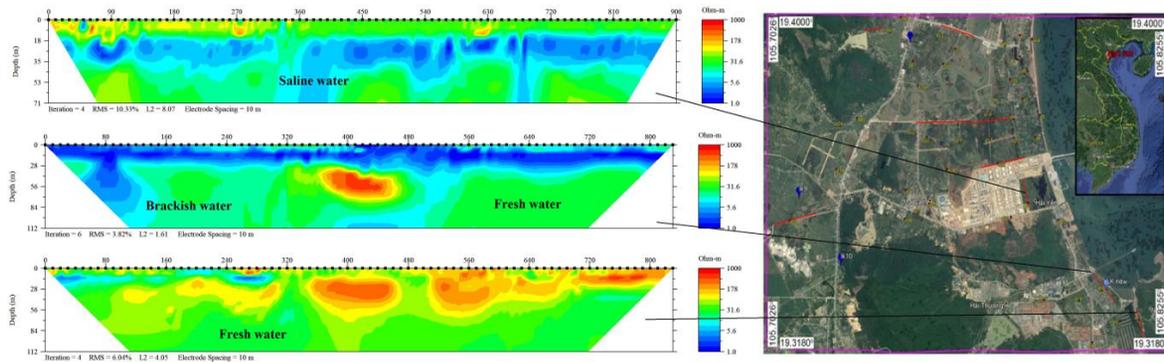


Fig. 5. The resistivity imaging profile parallel to the coastline at Nghi Son

Two RI profiles, which are perpendicular to the coastline, are shown in fig. 6 and fig. 7. The resistivity inversion uses the same resistivity color scale for each RI profile. Fig. 6 shows inversion result of RI profile located in the

centre part of study area. The inversion results show a change of formation resistivity equivalent to the depth of Pleistocene aquifer (fig. 6) at position of 900 m on the below RI section.

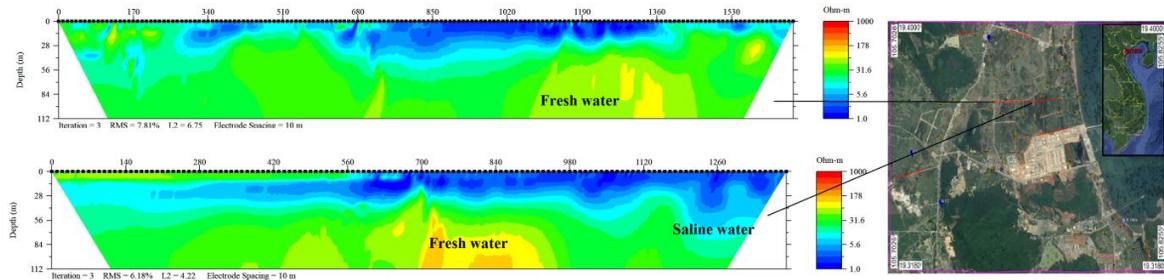


Fig. 6. The resistivity imaging profile perpendicular to the coastline at centre part of study area

A profile of RI investigation is located in the North part of the study area. The inversion results of RI sections show a slight difference in resistivity distribution. The above RI section gives a high resistivity of geological formation because this RI section is located close to the mountain area. The Pleistocene is found in a depth of 25 m and the fracture aquifer could be found from depth of 60 m to 100 m. On the other hand, a high resistivity of formation indicates that the Pleistocene aquifer contains fresh water along this profile. The below RI section has the same direction and is located close to the coastline (fig. 7). The distance between two RI sections is about two

kilometers. However, the resistivity distribution at this RI section is different. To compare the resistivity distribution of two RI sections, we choose a unified resistivity color scale. The Pleistocene formation is determined in the range from 55 m to 100 m of depth. The RI inversion shows a slight change of resistivity along this section. The resistivity values of Pleistocene formation vary in the range from 8 Ωm to 30 Ωm . It implies that the Pleistocene aquifer contains brackish and saline water (fig. 7).

The results of resistivity imaging survey determine the boundary between fresh and

saline water in the Pleistocene aquifer. The resistivity of the Holocene formation also implies that the Holocene aquifer contains both brackish and fresh groundwater. Based on the distribution of formation resistivity, which is derived from 1D and 2D geoelectrical investigations, the hydrogeological situation at the investigated site can be determined. The geoelectrical surveys in Nghi Son area show that

the fresh water can be found in the Western and Southeast parts of the study area in the Pleistocene. Along the coastline in the Northeast part of study area, the Pleistocene aquifer contains the saline groundwater. It implies that a saline water intrusion is occurring along the coastline of the Northeast part of Nghi Son economic zone.

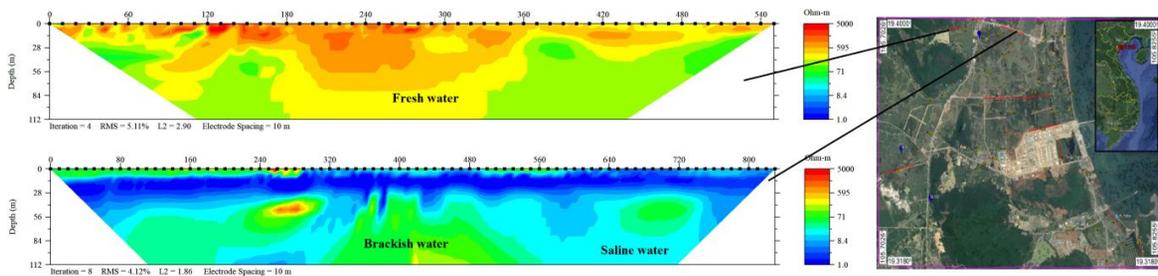


Fig. 7. The resistivity imaging profile perpendicular to the coastline at North part of study area

CONCLUSIONS

The Resistivity Imaging (RI) and 1D Vertical Electric Sounding (VES) have proved to be appropriate tools to investigate 2D structure in the coastal areas where have low resistivity of subsurface. The resistivity distribution results provide high resolution of 2D geological structure. The boundary between fresh and saline water in the Pleistocene aquifer is estimated. The fresh groundwater bearing formation maybe corresponds to the formation which has the resistivity above 20 Ω m. The 2D resistivity distribution presents the low resistivity anomalies which may be related to the hydrogeological windows or geological fractures. The saline water intrusion along the coastline of Northeast part is estimated referring to the low resistivity distribution of the Pleistocene formation in 2D RI investigations.

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