



Geophysical site assessment of soil and the rock structure in karst terrain using 2D and 3D mapping of noninvasive electrical resistivity tomography—southwestern of MO, USA

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Abstract

Electrical resistivity tomography (ERT) data were collected in a heavily Karstic area in southwest MO. The interpretation of the study has highlighted that the data of electrical resistivity tomography was abrupt by the multichannel analysis of surface wave data and the restricted drilling control. The study's primary goal was to ascertain whether variations in shallow rock and soil were associated with the terrain's topography. The first objective of this research is the establishment whether the topography of the rock's surface correlates with the paths used for surface drainage or not. The second objective is the exploration of the zones that mainly have low resistivity, particularly in karst terrain, and to analyse if these zones are somehow connected with sinkholes and solution-widened joints. The third objective is to comprehend and conduct an extensive assessment of soil and rock structure with the help of 2D and 3D mapping of the noninvasive ERT, and the fourth objective is to assess the geological and hydrological conditions and to analyse the flow patterns of groundwater underground and the surface drainage paths. The analysis of data has primarily shown that, except for soil near interpreted prominent joint sets, the resistivity values of shallow rock beneath and close to natural and man-made surfaces are typically lower than those of soil and rock elsewhere. It was determined that because moisture penetrates the subsurface in greater quantities along superficial flow trails than elsewhere in the research region, rock and soil resistivity beneath manmade and natural drainage channels is frequently abnormally low.

Keywords Karst · Geophysical assessment · Drainage pathways · 2D ERT · 3D ERT · Seepage

Introduction

Karst terrain is extremely challenging when compared with other topographies and formations, and challenges such as collapsing of karst features, soil erosion, and increased bedrock joints have arisen when analysing and carrying out the evaluation of the dissolution of these terrains (Daibo 2017).

The site that is being evaluated in this article is mainly present on the Springfield Plateau and entails Paleozoic carbonate with closely parallel sandstone, which is achievable for the creation of karst topographies, shale, stonework, and dolostone with added sandy rock, which covers the metamorphic and igneous rocks (Anderson et al. 2006). It is also triggered by Precambrian crystalline rock, and the basement of Precambrian is superimposed by the sandstone Cambrian Lamotte Formation. Moreover, all the layers of sandstone are protected by around 200 ft of Bonneterre dolomite as well as covered by around 150 ft of Davis Formation shale. Bonneterre dolomite 200 and 150 ft of Davis Realisation shale surround and protect the sandstone. The Davis Formation shale is covered by about 500 ft of dolomites from the Potosi Materialization Derby-Doerun Development and Eminence Development. Dolomite from the Eminence Formation is the most ancient rock type. To locate the atypically areas that have low resistivity in karst terrain that is located beneath naturally occurring and artificially constructed surface

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runoff drainage paths by comparing them to the resistivity values of the rock and soil found elsewhere on the site (Daibo 2017). Another study by Derek and Paul (2007) has highlighted that when water dissolves soluble bedrock, such as gypsum, limestone, dolostone, marble, and halite, a unique type of terrain known as karst arises. Sinkholes, shafts, sinking streams, underground drainage networks, and caves are the primary physical features of karst environments. Karst's distinctive characteristics are mainly the consequences of the interplay between climate, hydrology topography, and biological and geology elements. Karst can originate at all angles and elevations, and it may be present in the rock types that make up around 20% of the earth's land area. In addition, the past study by COŞKUN (2012) has emphasised that, in comparison to other subterranean topographies and constructions, karst terrain is quite difficult. When measuring and appraising the attrition of these landscapes, several issues come up, including the possible failure of karst features, the classification of the soil's substantial solution-widened gaps, as well as soil's destruction into the joints of bedrock.

To describe the subsurface underneath the place and ascertain whether disparities in the humidity content of superficial rock and soil are connected to ground outward topography, the method of ERT was used for the investigation of this location (Chukwunonso 2016). Dolomite makes the lower and upper parts of the aquifer. However, the water levels of Ozark aquifers are typically much below the surface of the ground (Bou-Hamdan and Abbas 2022). High units of yielding dolomite typically have significant secondary permeability and porosity because slightly acidic groundwater has partially dissolved the rock, enlarging the cracks and holes in the bedding plane (Jon Robinson and Neil 2008). A tiny area of central MO south of the Missouri River and the southwest corner of the state are both covered by the province of Springfield Plateau groundwater. The majority of southwest MO is thought to be a liberated aquifer, where the top permits surface water from permeating the clay and reaching the substratum. The articulated substratum is also regarded as secondary permeability and plays a significant role in the widening joint procedure (Bou-Hamdan and Abbas 2022). According to studies in the US Geological Survey, an aquitard formed by low-permeability components amid the Ozark Aquifer and the lower Springfield Plateau Aquifer significantly reduces the amount of water that may move vertically amid the two aquifers. Apart from that, the regional climate has a significant impact on Karstic landforms because it regulates water flow regimes' recharging (Hiltunen and Roth 2004). The main aim of the carried-out research is to emphasise the complete organised examination of an area of the project to signify and draw all the probable manifestations of karst features, examining and

accessing the hydrological and geologic circumstances to determine the association and interconnection values of resistivity underneath the pathways that are used for the drainage by mainly measuring the value of resistivity in regions relating to humidity content and associating consequences to resistivity values of soil and rock besides all through the site.

This study is of great significance as it mainly determines if any variations are present in the moisture area of soil and shallow rock. This study is also highly significant as it demonstrates the zones of low resistivity in karst terrain (Bou-Hamdan and Abbas 2022). This research study is of utmost importance as the past literature has shed light on the soil and rock structure, but little literature is found in analysing the soil and rock structure in Karst Terrain of the USA using 2D and 3D mapping and aids in filling in the research gap. The main goal of the research is to evaluate whether dissimilarities present in the humidity content of narrow materials such as soil and rock are connected to ground superficial topography by employing the ERT method for this investigation. This study is also significant because it demonstrated how groundwater seepage along both natural and man-made surface drainage pathways could occasionally lead karst topography to have zones with abnormally low resistivity. The investigation's findings also demonstrate that not all karst terrain zones with abnormally low resistivity are associated with sinkholes and solution-widened joints. The interpretation of electrical resistivity tomography data obtained in karst terrain should consider the potential effects of ground surface topography rather than presuming that all low resistivity patterns are related to karst processes. The study has also evaluated the several challenges that arise when monitoring and evaluating the erosion of these landscapes, including the potential failure of karst structures, the classification of the soil's considerable solution-widened gaps, and soil erosion into bedrock joints. This evaluation will help future researchers to work on different dimensions in future.

The main aim of the study is to carry out a comprehensive assessment of all the soil and rock structures by the utilisation of noninvasive electrical resistivity tomography in 2D and 3D mapping. The objectives of the research are to establish whether the topography of the rock's surface correlates with the paths used for surface drainage or not, to explore the zones that mainly have low resistivity, particularly in karst terrain, and to analyse if these zones are somehow connected with sinkholes and solution-widened joints, to comprehend and conduct an extensive assessment of soil and rock structure with the help of 2D and 3D mapping of the noninvasive ERT and to assess the geological and hydrological conditions, and to analyse the flow patterns of groundwater underground and the surface drainage paths.

Geology of the study area

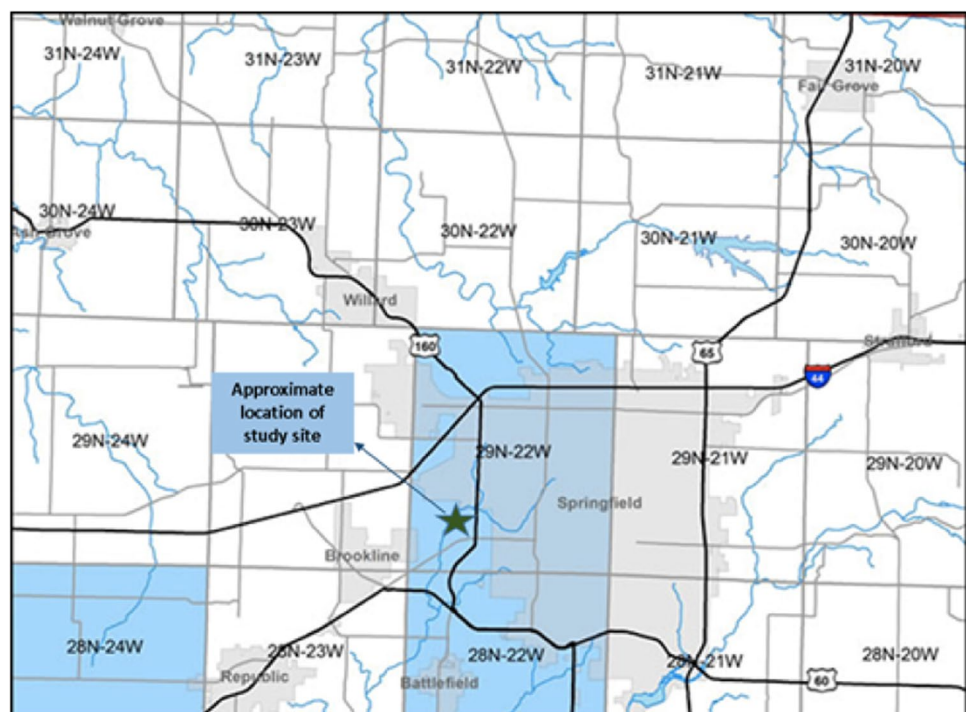
The location considered in this study is southwest of the crossroads of highways 60 and 160, directly to the north and west (Fig. 1). In particular, where there is the presence of the Springfield Plateau aquifer at the surface, a significant portion of the terrestrial in southwest MO is made up of low, round peaks with tributaries, mechanisms, and different karst characteristics like sinkholes. The research site has a humid climate with mild warm summers and winters. The annual rainfall on the average rate is 40 inches, and the annual air temperature average is 55 °F. The majority of the soils at the research location are residue. The place's loams are usually low-inclined and reasonably well-drained (Ismail and Anderson 2012). According to the US Geological Survey, approximately 15,981 sinkholes have been examined in MO. In the research site, karstic characteristics like hollows, mechanisms, and sinkholes are well accessible. In the southwest, more than 2500 sinkholes and 245 caverns have been discovered, and it is presented in the comprehensive plan of Greene County 2007 (Coots 2013).

The network of underground caverns may lead to the settling of the layers in different ways above and the formation of fresh sinkholes from the explanation of fractures and air-filled voids. Surveys were used to gather data from the depth of the bedrock to the highest, and the associated likely matters of the wider joints district may influence the constancy of the project under study.

According to the geotechnical investigation regarding the drilled boreholes at the site study, the bedrock is highly melted Burlington-Keokuk limestone, distinguished by the occurrence of cutters, high points, and cavities. Other than that, these features show that varies of bedrock's depth and are lateral variations of karst features. The shallower Springfield Plateau aquifer and Ozark aquifer are separated by low-permeability units that create an aquitard and severely restrict the vertical water exchange between the two aquifers (Bou-Hamdan and Abbas 2022). Besides that, the formation of North View and Compton Limestone make up the Ozark confining unit, which is present throughout most of the area. Despite poor hydraulic conductivities, these devices permit some water to pass through them.

The research area is located on the Springfield Plateau, which comprises approximately horizontal limestone and Paleozoic carbonate, which can form karst topographies, sandstone, and shale that sits on top of the metamorphic and igneous rocks. Besides, the study location is in a region where Burlington Keokuk Limestone motivates the ground (Bou-Hamdan 2020). Moreover, the below table provides a list of the stratigraphic and geologic units at this study site. The Precambrian crystalline rock-covered Springfield Plateau is the site that is considered in this study. In addition to that, the sandstone formation of the Cambrian Lamotte lies on top of the Precambrian basement. Dolomite from the Eminence Formation is the period's final remnant. Overlying the 25 ft of Gunter development sandstone is a 350-ft-thick

Fig. 1 The route location is 60/160 research sites



layer of lower and higher Ordovician-aged Gasconade dolomite Bou-Hamdan (2021), the study highlighted that seismic surveys, sediment core collecting, and outcrop observations are the principal methods used to study stratigraphy. Most often, groups like the International Ocean Discovery Program (IODP) use a ship specifically designed for drilling to gather sediment cores from the ocean floor. Geologists can subsequently study the recovered sediment or insert equipment into the drill hole to gauge the sediment’s geologic characteristics. After that, the cores are kept at locations around the world so that scientists can request samples from them.

The province of Ozarks Plateaus is physiographic south-westerly, and the sub-province of Springfield Plateau is where the study area is situated. (Bou-Hamdan and Abbas 2021). The limestones of Mississippian-age and limestone of cherty that concealment the bedrock surface are profuse, and they are located atop the Cambrian-aged and Ordovician layers shown in Table 1.

The formations of the Mississippian stratigraphic column show that limestone makes up the formation, which is older than the Mississippian (Table 1). The cross-section depicts the adjacent circulation of Mississippian-aged foundations all over southwest MO that were endangered by various external and internal actions and events, which significantly impacted these foundations and caused widespread disruption. Internal processes have caused the folding and faulting of these formations (Fig. 2). In contrast, the wide-ranging

trouble of the subsurface strata and outcropping has been caused by external processes such as erosion and weathering. This has ensued in projecting karst topography, which includes widespread cave schemes, sinkholes, subversive drainage classifications, and the spreading of linkages of these materialisations (Middendorf et al. 1987). Geologists recover sediment cores, and the core and the hole it came from are analysed using numerous studies. After the drilling is complete, geologists will place an instrument to measure various physical characteristics. These readings could happen frequently or sometimes. Measurements of natural gamma radiation, resistivity, conductivity, density, porosity, and other properties are common. Geologists use these qualities to discover as much as possible about rocks or silt. Physical characteristics can also be used to connect sediment cores. Geologists develop these correlations to facilitate the comparison of sections from various origins. (Bou-Hamdan and Abbas 2021).

Methodology

Boring holes are frequently used as a form of sinkhole investigation (Mouici et al. 2017). Holes used to be drilled during the research into sinkholes. While the data has been collected, borings drilled in the study location seem to be used to collect information. Although, getting the subsurface reality appears to be the objective to limit the data interpreted by

Table 1 Units of geology and stratigraphy in the study region (Vandike 1993)

System	Series	Group	Formation	Thickness (ft)	
Mississippi	Osagean		Burlington-Keokuk Formation	150-270	
			Elsley Formation	25-75	
			Reeds-Spring Formation	125	
			Pierson Formation	90	
	Kinderhookian	Chouteau	Northview Formation	5-80	
			Compton Formation	30	
Ordovician	Canadian		Cotter Formation	600	
			Jefferson-City Formation		
			Roubidoux Formation	150	
			Gasconade Formation	Upper Gasconade Dolomite	350
				Lower Gasconade Dolomite	
Gunter Sandstone Member	25				
Cambrian	Upper		Eminence Formation	500	
			Potosi Formation		
			Derby-Doerun Formation		
		Elvins	Davis Formation	150	
			Bonneterre Formation	200	
			Lamotte Formation	150	
Precambrian		Crystalline rock			

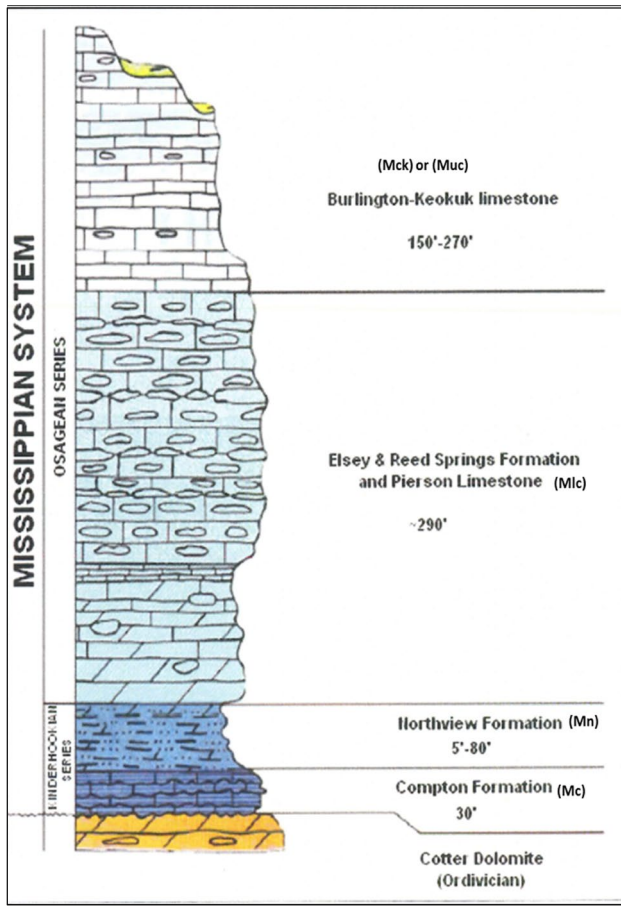


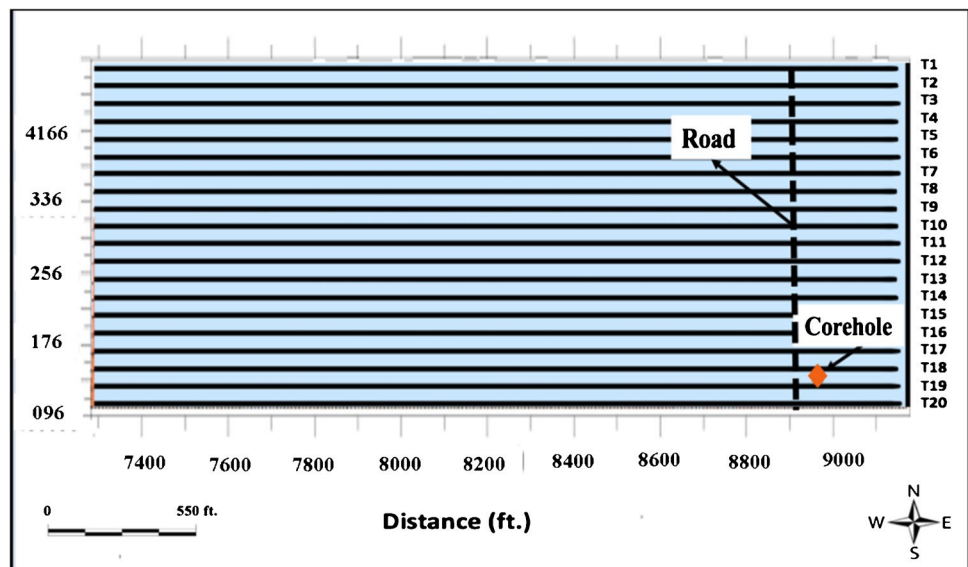
Fig. 2 The Mississippian system stratigraphic column in the study site

ERT data (Dahlin and Loke 2018). The somewhat uneven bedrock surface and joints that are expanded beneath the site seem adequately depicted by boring log data. The findings corroborated the data, highlighting that the depth to the top of the rock was shallow, varying from 5 to 35 ft. Although rock disintegration has been extensively investigated, the source rocks' remaining soils have received far less attention. Every component of residual soil qualities is impacted by weathering, although it is still unknown how it affects soil disintegration behaviour. In this work, natural granite residual soil (GRS), collected at various levels, was subjected to laboratory disintegration tests utilising a self-developed technology (3.5–17.5 m). The disintegration process was quantitatively tracked through several indicators representing the degree and pace of soil disintegration (Elmo et al. 2022).

To connect with and comprehend ERT data, coreholes appear to be included in the study region using hollow-stem augers with H.Q. coring (Leuschen et al. 2018). However, Fig. 3 shows the core hole that has been used in this experiment. Additionally, no voids were found, rock quality (RQD) ranged from usually satisfactory to superb, and fractures were typically horizontal.

Electrical resistivity tomography data were collected in southwest MO's extensively karstic region. The ERT approach is a time-saving, reasonably priced, and labour-intensive environmental and geotechnical engineering technique. Applications for ERT data include measuring bedrock depth, tracking groundwater levels, and gathering information on soil thickness. The ERT approach is favoured in the characterisation of karst characteristics, according to Zhou et al. (1999). If properly integrated with geology information and initial site examination, ERT procedures are successful in sinkhole inquiries. By taking capacities on the earth's

Fig. 3 Location of core holes drilled in the research area



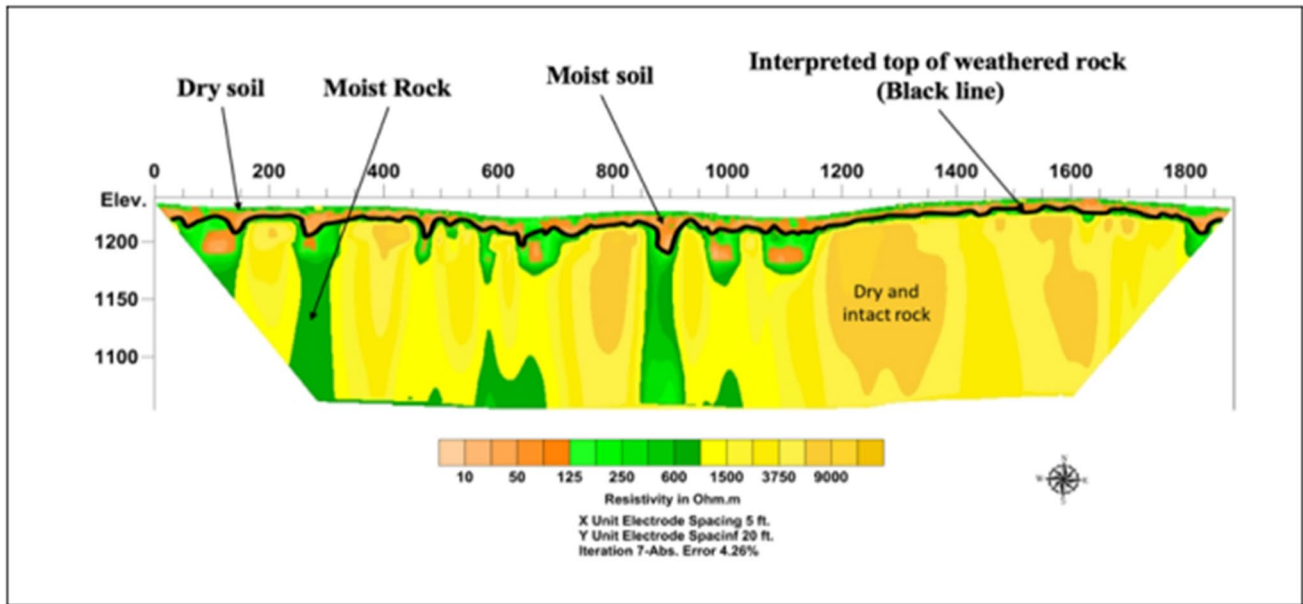


Fig. 4 The interpreted ERT profile in the study area shows that the contour interval of (125 Ω -m) corresponds to the supposed top of the rock, which is weathered (highlighted black line). More than 125

Ω -m resistivity values are correlated with dry soil. The rock segment that matches resistivity values (> 600 Ω -m) is thought to be primarily dry and possibly more undamaged

superficial, surveys on electrical resistivity aim to ascertain subsurface resistivity distribution. These observations can be used to estimate the actual resistivity of the subsoil (Bou-Hamdan 2020).

As a proper geophysical technique for identifying the karst terrain features, ERT examines the subsurface’s spatial

changes in the soil and rock electrical resistivity. Besides that, the best geophysical process for finding subsurface dissolution areas and sinkholes and assessing the foundation’s depth is the ER tomography methodology, by which the spatial fluctuations of resistivity and values of soil and rock below the surface. The electrodes of ERT in this investigation were placed

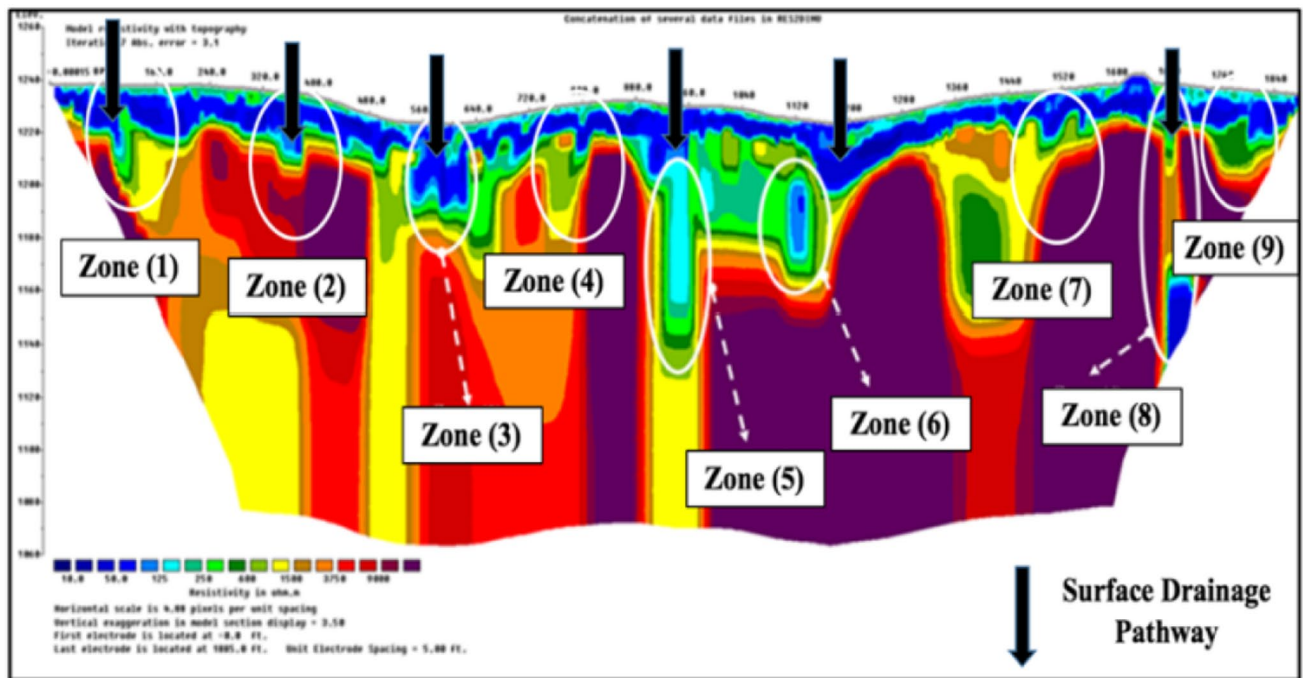


Fig. 5 An uninterpreted west–east oriented 2D ERT profile revealed the low resistivity zones (1, 2, 3, 4, ..., 9)

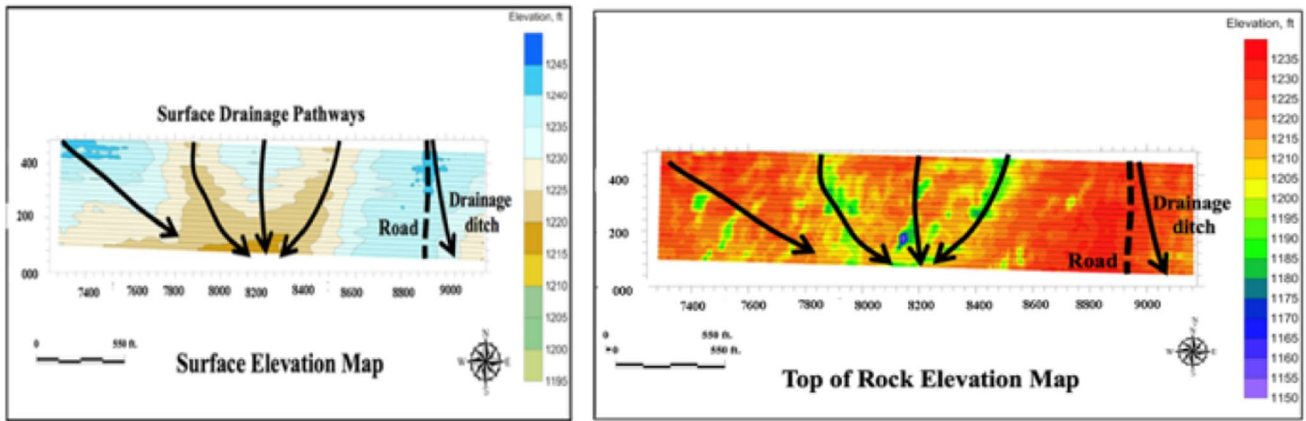
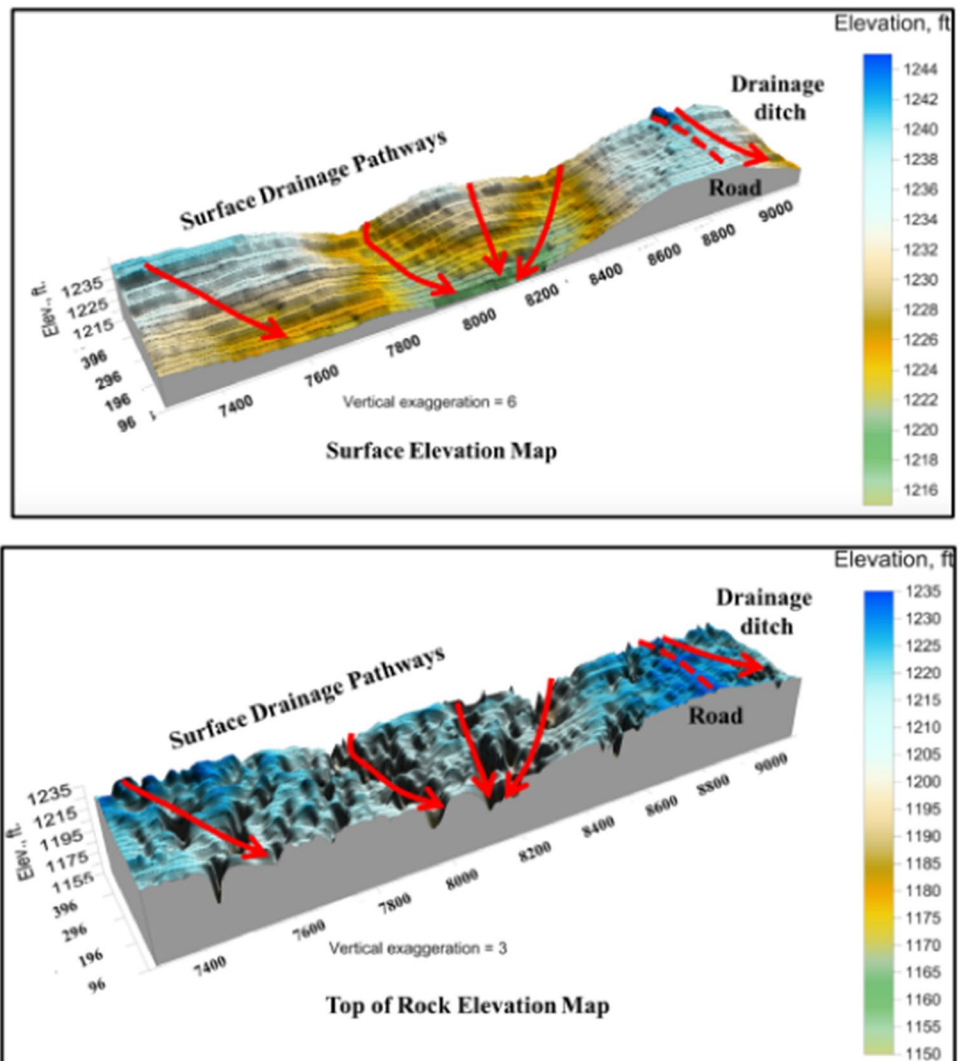


Fig. 6 Surface elevation map and west–east orientated 2D ERT profile with interpreted weathered rock topography

Fig. 7 Surface elevation contour map connected to surface drainage pathways (red arrows). **b** A map relating the elevation of rock surfaces to the patterns of surface drainage pathways (red arrows). Elevations and distances are in feet



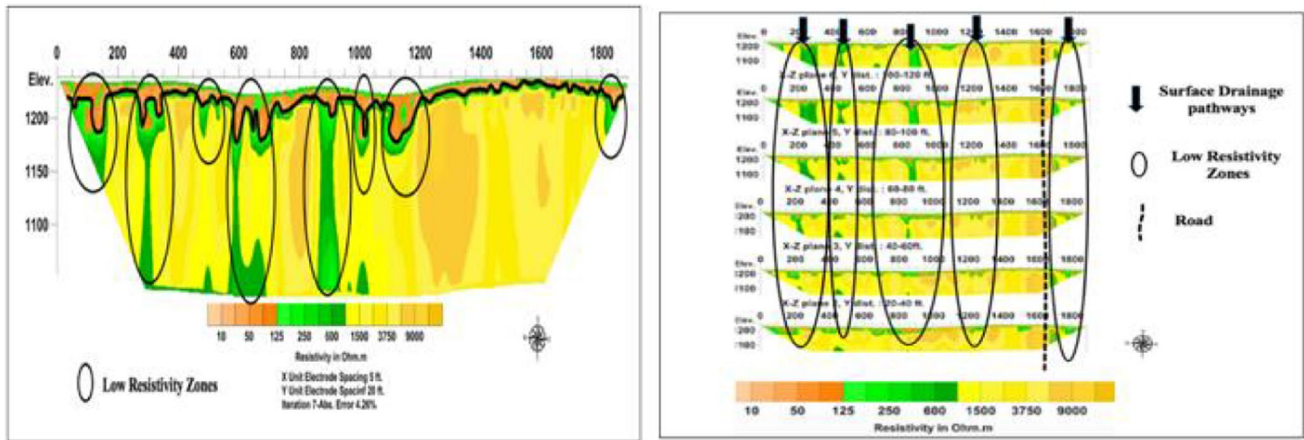
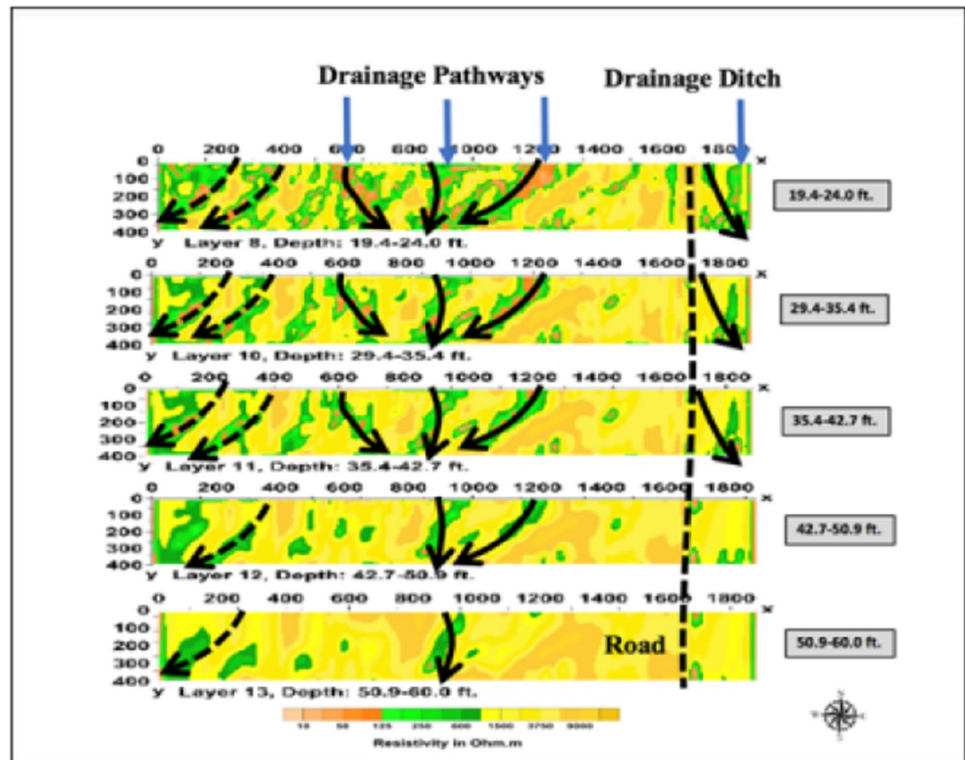


Fig. 8 3D ERT profile with a west-to-east oriented top of weathered rock

Fig. 9 A series of horizontal depth slices generated from the 3D ERT data for the study site reveals the seepage pathway directions associated with lower resistivity values



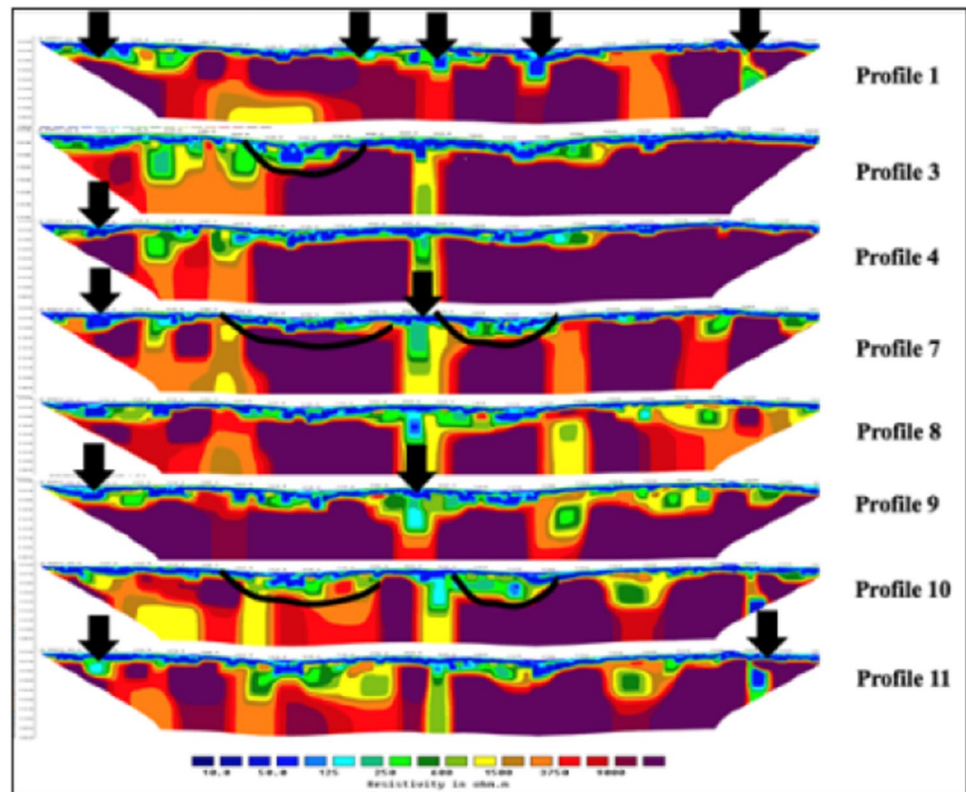
5 ft apart. More electrodes can improve depth determination rather than more expansive spaces between them (Zhu et al. 2022). Typically, there is an inverse relationship between spacing in electrodes and imaging depth.

Results and discussion

The study of Dimechet et al. (2022) has highlighted that the potential of electrical resistivity tomography for investigating placers has not been fully explored, despite its

widespread use in prospecting and mining gold deposits. Working with alluvial placers in Kamchatka, Altai, and the Baikal region led to the conclusion that electrical resistivity tomography has a high resolution for resolving geological issues, making it suitable for use as the primary technique for prospecting and exploring placers (Junaid et al. 2022). Designs have been used to visualise and analyse the location’s possible karst development and sinkhole collapse (Ducut et al. 2022). The data was gathered using the ERT method along parallel, independent traverses that faced west and east (Alfuqara 2017). Since the joint sets’ primary

Fig. 10 W-E-oriented 2D ERT profiles



orientation was north-south, this traversal orientation was chosen. ERT data were gathered from imaging the subsurface, mapping variations in the rock's topography, mapping variations in the thickness of the soil, characterising joint sets and potential sinkholes, monitoring groundwater flow patterns beneath the surface, and analysing the properties of the rock and soil. ERT is an excellent geophysical instrument for studying sinkholes (Wightman and Zisman 2008). The study of Xia et al. (2022) asserted that combining ERT with boring data is a superior method for analysing karst features. However, ERT data profiles have been analysed to highlight the traits of likely solutional sinkholes. Due to the extremely high resistivity contrast between undisturbed soil, carbonate rock, clay in-fill, and air-filled holes, ERT is frequently utilised in karst terrain in MO (Ismail and Anderson 2012).

Data has been collected from the ERT method, and rock boreholes at the site showed that the rock is severely weathered. The ERT profile's 125 ohm-m resistivity contour value corresponds to the predicted top of the weathered rock (Fig. 4). As a result, moisture and high clay content are mostly to blame for the low resistivity zones shown in the ERT profile (Youssef et al. 2021).

The interpreted ERT profile in the study area shows that the contour interval of 125 Ω -m corresponds to the supposed top of the rock, which is weathered (highlighted black line). More than 125 Ω -m resistivity values are correlated with dry soil. The rock segment that matches resistivity values

(> 600 Ω -m) is thought to be primarily dry and possibly more undamaged (Fig. 4).

Hasan and Shang (2022) highlighted that the earth's surface breakdown or dissolution of rocks and minerals is weathering (Fig. 5). The data obtained demonstrated that the subsoil rock is heavily and severely fragmented. The conductivity of rock increases when there are numerous fractures below the surface of drainage routes and where clay is common. When the moisture level is high, moisture in porous, permeable, cracked rock typically reduces resistivity values while boosting rock conductivity. In the studied area, which appears to have been scanned by a 2D ERT profile with an interpreted west–east orientation, significant fissures have been observed beneath the surface of drainage channels of low resistivity zones (Fig. 6). The zones of low resistivity have been seen in the study area, as shown in the figure. It is observed that additional low-resistance regions are unrelated to the surface of drainage pathways, as seen in Fig. 6.

The image showed that system of drainage (Fig. 7). Maps depicting the ground surface elevation, elevation of the top of the rock, and soil thickness in the study area are based on the interpretation of ERT data. Using 1215 to 1244 ft are the ground surface elevations that can be calculated from ERT profiles. The soil thickness in the location, which also represents the depth to the top of the rock, ranges from 5 to 35 ft. The elevation of the top of the rock is between 1150 and 1235 ft. Figure 7 shows the surface elevation and top of

Table 2 Summary of findings

Electrical resistivity tomography data	<ul style="list-style-type: none"> • The prospective of electrical resistivity tomography for investigating placers lacks exploration • Linear anomalies with high electrical resistivity resemble gold-promising as seen in a floodplain • The ERT was very high while working with the alluvial placers in Kamchatka and Altai • Combining ERT with boring data is an exclusive for analysing karst feature
Bedrock topography	<ul style="list-style-type: none"> • ERT method and rock boreholes at the site showed that the rock is severely weathered • ERT profile's 125 Ω-m resistivity contour value resembles the predicted top • Moisture and high clay content mostly cause the low resistivity zones • Subsoil rock is heavily and severely fragmented • With high moisture levels, moisture in porous, permeable, cracked rock typically reduces resistivity values while boosting rock conductivity • Significant fissures have been identified below zones of low resistivity in channels of drainage • Changes in moisture content, which are the reflection of intensively fractured rock dissolving underneath the surface, are implied by variations in rock elevation • Surface topography is a mirror of the surface of bedrock in relation to draining pathways
Soil mapping	<ul style="list-style-type: none"> • Higher resistivity values predict that the shallower part of the soil is dry • Lower resistivity measurements in deeper areas, pinpoint the soil/rock contact, indicate the depth
Joints and fractures	<ul style="list-style-type: none"> • The rock is pervasively fractured and has low resistivity values because of moisture from surface drainage seepage, as seen by the parallel 20 west–east ERT • Higher moisture content determines the zones with lower resistivity values • Resistivity levels range from low to high, increase with depth and are correlated with seepage directions

rock elevation contour maps related to the surface drainage channel patterns of the site. Changes in moisture content, which are a reflection of variations in the rates at which intensively fractured rock dissolves beneath the surface, are implied by variations in top of rock elevation. The acquired data revealed that the topography of the surface is a mirror of the bedrock surface, related to the significant correlation with surface drainage pathways (Fig. 8). The surface and the top of the rock throughout the site were dissected by weathering.

Due to the presence of relatively shallow soils, the soil thickness in the research region ranges from 5 ft to around 35 ft. Higher resistivity values suggest that the shallower part of the soil is dry (Gou and Miller 2014). Lower resistivity measurements in deeper areas, which show that they are moist and can be used to pinpoint the soil/rock contact, indicate depth (Fig. 8). The more solid the soils are and the narrower the available piping is, the less permeable they are due to the piping of fine-grained soils and clay.

The rock is pervasively fractured and has low resistivity values because of moisture from surface drainage seepage, as seen by the parallel 20 west–east ERT. Some ERT resistivity profile measurements alter anomalously as a result of lateral variations in the moisture and clay content (Fig. 9).

The ERT profiles in Fig. 9 show how the highly fractured rock is dissolving to show the development of the process. Typically, where drainage channels are available, the widest dissolving widths develop. However, higher moisture content determines the zones with lower resistivity values, which are represented by the drainage channel directions,

as shown by the depth slice sequence in Fig. 9. Typically, resistivity levels range from low to high, increase with depth, and correlated with seepage directions. Both vertical and horizontal designs can be used to track the groundwater flow system and seepage direction. E-oriented 3D-ERT profiles are used with the dissolution site via intensively fractured rock and low resistivity values (Fig. 10).

Figure 10 shows the seepage pathways that are associated with lower resistivity values displayed in a series of horizontal depth slices for the study region that was created using 3D ERT data. Depressions in the area are characterised by lower resistivity values. The seepage pathways that changed horizontally (black lines) and vertically (black arrows) were represented in W-E-oriented 2D ERT profiles that can be used to monitor the seepage direction and the groundwater flow system (Fig. 10).

W-E-oriented 2D ERT profiles can also be seen for better results. The directionally varying horizontal (black lines) and vertical (black arrows) seepage pathways seemed to be associated with variations in resistivity values. No potential air-filled voids were characterised throughout the site.

This study has focused on carrying out a geographical site assessment of soil and rocks in a karst terrain by primarily using 2D and 3D mapping in the southwestern region of MO, USA. The findings from the study could have been detailed and extensive if data had been collected from other areas and could not be carried out due to limited time and resources. This research has also taken assistance from the past literature, and the research insights taken from individuals could have been beneficial when extracting productive

outcomes for the carried-out research. In addition, future research can also focus on other areas of the USA for a detailed assessment of the geographical locations with the help of 2D and 3D mapping.

Conclusions

The data acquired at the site showed that groundwater seepage flowing along both natural and artificial surface drainage channels can result in zones of anomalously low resistivity in a karst topography. It has been analysed that the rock beneath the subsurface is pervasively fractured. But where deeply fractured rock is found, such as in zones of solution-widening joints, below the surface of drainage pathways, or in zones with clay. At those places, rock conductivity increases due to high moisture levels. The resistivity of soil and rock beneath natural and artificial drainage pathways is frequently low throughout the study, according to the ERT method, because more moisture seeps into the subsurface along surface flow pathways than anywhere else in the study area.

ERT data show that fluctuations in the moisture content of shallow rock and soil are related to ground surface topography, with the exception of soil and rock adjacent to expected significant joint sets. Thus, the findings of this study show that junctions that have been widened by solutions and sinkholes are not the only causes of low resistivity zones in a karst topography. The influences of ground surface topography should be taken into account when interpreting obtained ERT data in karst terrain rather than just assuming that all low resistivity characteristics are related to karst processes. The unique features of karst are primarily the results of interactions between climate, hydrology, terrain, and biological and geological factors. Karst may be found in the rock types that make up about 20% of the earth's land surface. Karst can arise at all angles and elevations. The study has also highlighted how challenging karst terrain is compared to other subsurface topographies and buildings (Table 2).

It is recommended that consideration of water flowing in the seepage of the natural and artificial channels of drainage requires the consideration of including the groundwater topology as the primary function for analysing the lower resistivity.

There is another factor that requires attention in analysing the ERT data, and that is the ground surface topology, as this is an excellent consideration in the interpretation of the data. It has been included in the current context of operation for better inclusivity and diversity in the system, making the possible changes in the overall structure for data collection and then its interpretations.

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Declarations

Conflict of interest The authors declare no competing interests.

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