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Time Geography, GIS and Archaeology

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We argue that time geography can offer a conceptual and methodological framework for conducting accessibility constraint analyses that can be implemented within GIS. We present the use of cost-surfaces to implement time geographical concepts, especially the time-space prim and its derivates, cumulative potential path areas and potential path fields. The tools should not be understood as mere descriptive devices, but means for deeper understanding of social processes in a material world.

Keywords: Time geography, archaeology, GIS.

1. Introduction

The applications of cost surface analyses in archaeology, such as analyses of site catchments, optimal paths, etc. usually, implicitly or explicitly, invokes the theoretical assumptions about rational behaviour of agents and least cost principle, as the name of the "least cost analysis" implies.

However, we argue that cost surface analyses can have much more general analytical use in archaeology. Thus we turn for an inspiration to time geography. We present the basic principles of time geography approach and its possible relevance for archaeology.

The main goal of this paper is to develop new tools and approaches for understanding past landscapes, especially tools for the analyses of proximity, mobility, accessibility and interaction.

2. Time Geography

Time geography was developed by Torsten Hägerstrand and his associates at the University of Lund in 1970s although its roots can be traced further back in time (HÄGERSTRAND, 1970, 1973, 1975; PRED, 1977). Time geography is a powerful conceptual framework for understanding human behaviour in both time and space; in particular, it constraints and trade-offs in the allocation of limited time among activities in space. Time geography focuses on constraints imposed by corporeality of human existence in time and space, such as the fact, that nobody can be at two places at the same time, has only limited ability to undertake more than one task at a time, that movement is time consuming and "the fact that every situation is inevitably rooted in past situations" (HÄGERSTRAND, 1975; PRED, 1977).

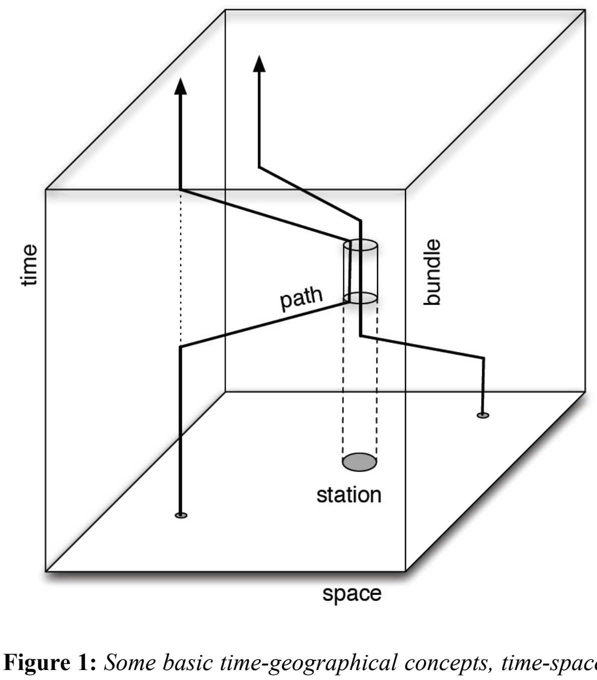

Figure 1: *Some basic time-geographical concepts, time-space aquarium, path, bundle of activities and station.*

Time geography has developed a series of analytical instruments to investigate how certain types of constraints have a structuring effect on everyday life (Figure 1). The most fundamental concept of time-geography is time-space, or time-space aquarium, a bounded three-dimensional space, where width and length describe two-dimensional space and depth stand for time. The time-depth of the aquarium may vary, from a daily, to yearly or biographical (lifelong) time scale.

Any physical body (thing, substance, animal or human person) within the space-time aquarium can be described by its time-space path or trajectory, which describes its, his or hers position and movement within the time and space. Thus, in time geography, time and space are inseparable.

However, more than isolated paths of agents are the space-time patterns that emerge from interactions and relations between agents or "the choreography of existence" (PRED, 1977), as the agents move on their projects, goal directed undertakings. These events or steps occur at physically fixed spatial units of observation such as stations or domains. There, two or more agents can form a group and join some shared activity and form an activity bundle. In this way an activity systems emerge that are stable, multi-scale spatiotemporal patterns formed from intertwined allocation of time among activities in space (PRED, 1981a, 1981b; LENNTORP, 2004).

In time geography the physical mobility is not understood in isolation, but instead as a component in a wider pattern of interaction. The physical environment where agents move around interacts with the capabilities of agents and thus plays an active role in the shaping of the paths and outcomes of their projects.

Thus Hägerstrand's concept of space-time is extremely powerful because it is very simple.

2.1. Time geography and archaeology

Affairs become more complicated if we try to apply time geography to the archaeological problems. Due to the fragmented nature and resolution of the archaeological record, the direct applicability of these concepts to archaeology is extremely limited. Except in outstanding cases, it is impossible to trace a time-space path of past persons.

However, Hägerstrand and other time-geographers point to the regularities in movement when they carry out their everyday tasks or projects that emerge as an activity system. Activity systems are patterns of daily, seasonal or lifetime routine movements, interactions and activities of agents (PRED, 1977, 1981a, 1981b).

Thus different persons tend, for various reasons and in various temporal scales, to move regularly in similar paths in time and space, for example, going to work,, traveling to the market, herding sheep, etc. Social practices or routines are normally conducted at definite places and at given moments (stations in time-geography speak) although some may extend over long periods of time. Thus social individuals tend to follow recurring time-space paths in their day- to-day lives. Routine practices are shaped by various forms of constraints, for example, the need for regular sleep and food, seasonal requirement of plants or animals, availability of tools, availability of other agents that form activity bundles, constraints imposed by the landscape itself, etc.

The routine practices of course also change stations where they occur; they leave material traces that create new constraints in the process. In this way they have a structurating effects on future practices that occur at the station or in the vicinity (FAHLANDER, 2003: 122-132). As Julian THOMAS (1996:90) puts it: "[w]hile peo-ple often move in cyclical patterns in the course of routine activities, returning to the same location again and again ... the places ... are themselves continuously being physically altered and decaying, as well as continuously being re-evaluated and re-interpreted".

The archaeological record is of course not a result of acts derived from a single person, but a cumulative effect of the practices. Thus, for example, agents on their daily routines have shaped and changed the settlements over a long time. The settlement is then a material residue of a bundle of special activities, which in turn, enabled other activities to occur in its vicinity.

Thus we can see the landscape as a network of stations, which are constantly reproduced as "collapsed acts" of persons moving and performing routines in time and space. This is close to Tim Ingold's (INGOLD, 1993) relation between the "taskscape" and landscape: "just as the landscape is an array of related features, so — by analogy — the taskscape is an array of related activities."

This forces us to explicitly address the notion of time, which in this case is not just a simple linear succession of events, but is itself structured and shaped by performance of tasks and produces different "temporalities", which are "collapsed" into landscape. Thus "[l]andscape is time materialized. Or, better, landscape is time material-izing: landscapes, like time, never stand still" (BENDER, 2002: 103). Landscapes are in a constant process of becoming (another temporality) through the daily, seasonal or a biographical time-space "ballet" of actors.

3. Back to GIS

As we said, due to the properties of the archaeological record it is generally impossible to trace a time-space path of past persons doing their daily routines.

Future paths of a past agents who performs activities at the site can potentially branch off in a number of directions. However, they are limited by constraints that work on them, such as maximal speed, availability of transport, etc. The *time-space prism* circumscribes a time-space volume where all trajectories must or can progress. Its shape is defined by constraints that operate on the individual. The prism thus discloses possibilities and focuses on these rather than as on behavior per se. This renders the concept, neutral and universal, applicable as it articulates a fundamental coherence in our world (LENTROP, 2004).

The space-time prism can exist between any pair of temporally adjacent points. In this case, there is an open temporal interval — time budget — during which the person can conduct travel and participate in activities. More generally, one or both of the origin or destination points may be unknown, or may be different locations. Projecting the time-space prism to the two-dimensional geographic plane delimits the *potential path area*, that is the set of geographic locations that the person can occupy during the available time budget (Figure 2).

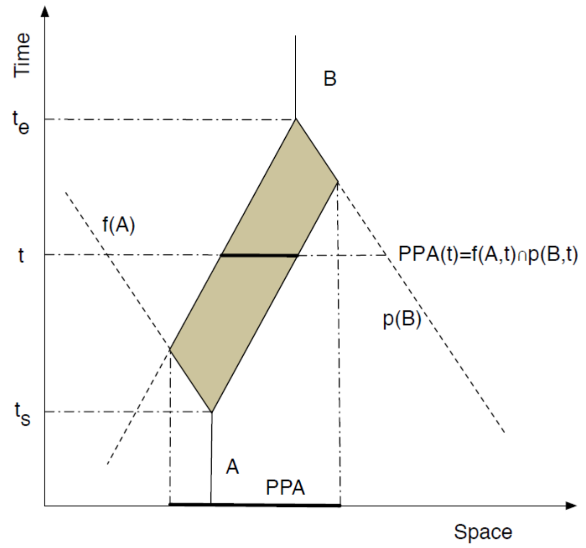

Figure 2: *The formal definition of time-space prism, where ts is start time, te is end time of activity, thus te-ts is available time budget. The f(A) is future surface from departure point A and p(B) is past surface to the destination point B. The potential path area at time t, PPA(t), is defined as intersection of future and past isochrones at the time t. The potential path area of prism PPA is therefore the union of PPA(t), where ts<t<te. (see HARVEY, 2005).*

Within GIS, cost surfaces can represent time of movement as space, based on the effect of landscape friction on the speed of movement. Thus the cost surface represents time of movement from the point of departure, and is shaped by the capabilities of agents and the limitations imposed by the landscape ("landscape friction"), usually expressed as a function of slope (for theoretically informed review of mobility see MURRIETA-FLORES, 2010).

The cost surface where the cost represents the traveled time from the starting point is an equivalent to the surface of the time-space prism with one know and one unknown point. We might call it the *future surface* (cf. HARVEY, 2005) as it represents the time-space surface of maximal possible extent of an agent at a given time after he departed from the starting point. In the case that the point represents the known end point, the cost surface represents the *past surface,* or possible locations at a given time before she reached the destination point.

Most of the widely used cost surface analyses in archaeology, for example the delimitation of isochrone surfaces around sites (GAFFNEY and STANČIČ, 1993), are therefore potential path areas of prisms, where agents return to their destination points within given time budget. These analyses can of course be produced using ready-made capabilities offered by standard GIS packages.

However, our goal is to model the general prisms explicitly as time-space entities.

Using three-dimensional capabilities of GRASS GIS, we developed a routine called *prism*, which represents the time-space prism as a three-dimensional object, based on movement friction, start and end points and allocated time. This procedure models the general prism: the departure and destination points can be different locations or even unknown ones. The prism is represented as a volume composed of voxels, where the third dimension represent the time from the departure point. Cost was expressed as time needed to cover the distance using the Toblers's hiking function (TOBLER, 1993). The study area is centered on the roman towns of Trea and Ricina in the Central Italy. The resolution of the DEM is 15 m, time resolution is 5 minutes.

The prism is constructed by sampling the future and past surface at a specific time interval (equal to the resolution on the time axis) and the intersection of isochrones (Figure 3).

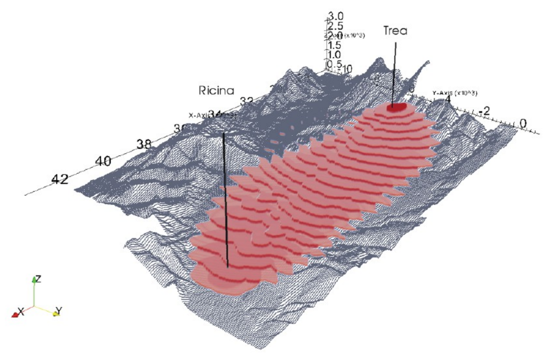

Figure 3: *The time space prism as a three-dimensional volume.*

In addition, we have implemented series of operations between those entities such as prism/path and prism/prism intersection, and a two-dimensional projection of the time-space prism (potential path area). Intersection is the condition when two or more time geographic features share some locations in space and time (HARVEY, 2005: 34). Thus the prism/path intersection returns the segment of the path (represented as a three-dimensional segmented line or polyline) that fits within the prism, and thus defines where and when interaction is possible. Prism/prism intersection defines time-space volume where and when agents can meet and bundling can occur. Therefore stations can exist only within intersections.

This enables us to perform the basic algebra on time-space entities.

However, in archaeological applications the use of time-space entities is neither always possible nor reasonable. The temporal relation between entities can dramatically change the shape of intersection volumes. Thus the interaction time-space is completely different if two agents start their routine contemporaneously or if one agent starts his routine after the first agent has already retuned to his destination.

This is the information we often do not have. The temporal relations between acts that formed the archaeological record are often lost. Thus, for example on a habitation site, we can establish temporal relations between exceptional events such as building, abandonment, reuse etc. The traces of the daily and seasonal "ballet" that happened between those major events are often "flatten" or "collapsed" into the use wear, traces, middens...

However we should never forget that this "flat", "compressed" time is result of time-space processes and practices and that temporal relation between practices can be extremely complex and important. Thus Evans PRITCHARD (1940: 101-102), for example, describes the Nuer seasonal round as "primarily the succession of pastoral tasks and their relation to one another". Even more, the temporal relation between practices can be seen as another constraint that operates on then. For example, within the agricultural cycle, sowing and harvest are temporaly exclusive but dependent on each other. Environmental archaeology has developed a number of tools and approaches which may determine the seasonality of a site from the organic finds (presence or absence of certain species), physical indices on the bones and teeth of animal remains, or, more recently, stable isotope analysis. Even with these impressive achievements, there have been very few attempts to temporalize this sequence apart from a divisions into well-defined discrete blocks of time, seasons and tasks associated with them. Time-geography and tools developed here can be useful in the analysis and visualisation of these seasonal "taskscapes".

However, when the information on the temporal relations between time-space prisms is unknown, it is the safest to assume that possible interaction occurs within the maximum possible time-space volume of interaction. Therefore we study the necessary conditions for the interaction and not the interaction as such.

Consequently, in many cases there is no need to keep the prism as a time-space object and we can only use it's spatial derivate, the potential path areas. So we are dealing with "flatten" or "collapsed" time of daily routines, represented as potential path areas (Figure 4). The potential path area is constructed by projecting the time-space prism on the flat surface, creating a binary map where values for each point indicate weather this point is inside or outside potential path area.

Potential path areas are thus an extension of iso-chrone analysis and enable us to create their intersections, see weather the sites lies within the potential path areas, etc.

However, there are also some more exciting uses of the potential path areas, which can reveal a more complex or deeper understanding of the social processes in the landscape. We developed two procedures for deriving cumulative potential path areas and potential path fields.

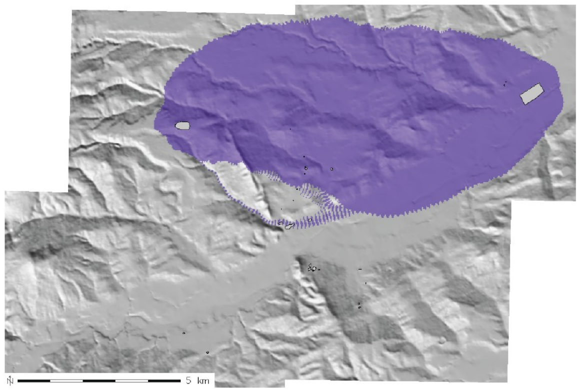

Figure 4: *The potential path area of the prism on Figure 3.*

3.1. Cumulative potential path area

We can construct the *cumulative path* areas by overlapping and adding different potential path areas from a set of starting points (Figure 5). It is constructed in a similar way as David Wheatley's "cummulative viewshed" (1995). Binary potential path areas using constant time budget around selected sites are added together. Thus the value of every cell in the cumulative potential path area map indicate from how many starting points it is accessible within an allocated time budget. By modifying the time budget we can observe its effect on the structure of possible interaction in the landscape. Thus we can measure how accessible parts of the

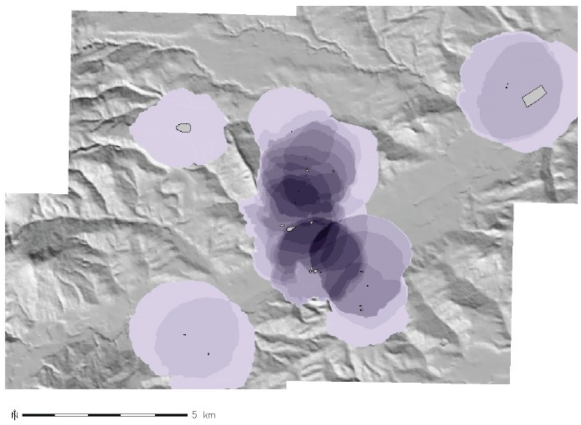

Figure 5: *30 min cumulative potential path areas around sites.*

landscape are from the different sites or bundles of activities. This shows how the sites structure the landscape, it can identify the places or areas where interaction is facilitate by the landscape, where bundles of activities can occur and where not, or where more time budget is needed to form a bundle. It can also help the identification of "non-events", or better, the barriers that prevent certain types of activities to occur (PRED, 1977: 210).

In this way we can see landscape as a vehicle for interaction and the ways daily practices structure the long-term material record in the landscape.

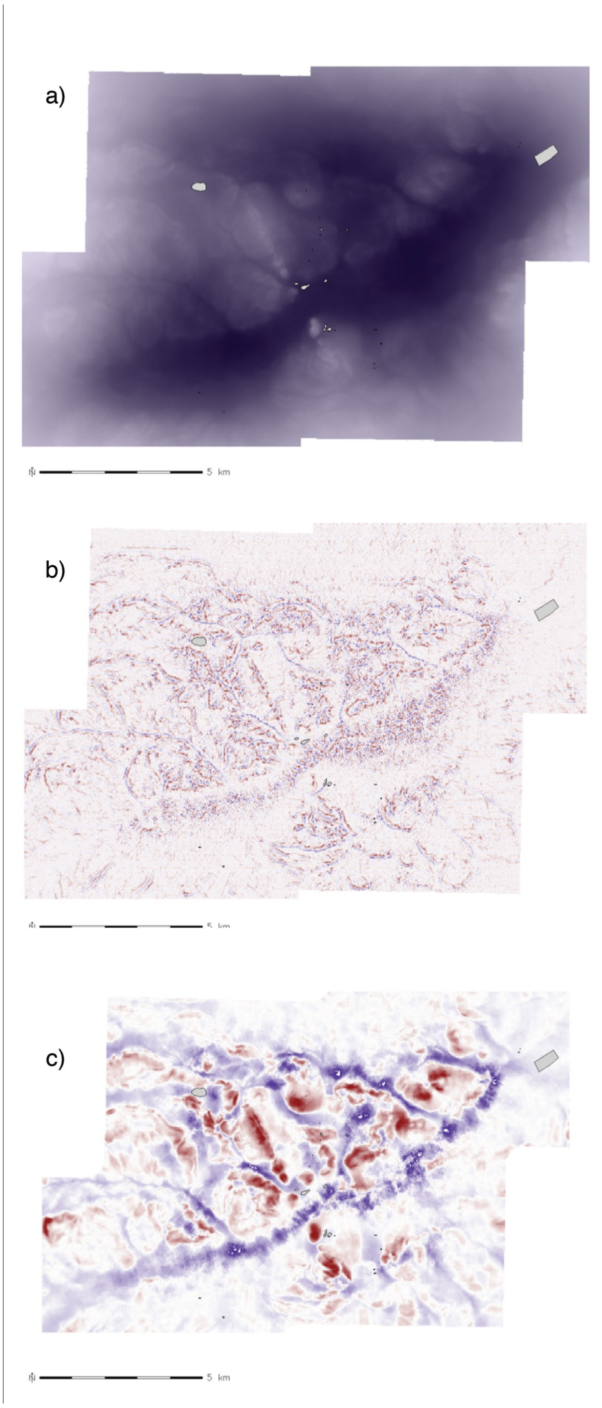

Figure 6: *30 min potential path field (a), its prominence within the 75 m (b) and 300 m (c) neighborhoods.*

3.2. Potential path field

Another tool we developed is *potential path field*, which is an extension of the previous one, an intersection of potential path areas within time budgets from every location in the landscape (Figure 6a). It is constructed by summing the potential path areas with constant time budget from *every* raster cell of the study area. In this way the potential path field is constructed in a similar way as Marcos Llobera's "total viewshed" (LLOBERA, 2003). The result is a continuous raster surface, where the value of each cell provides information from how many points , within given time budget is accessible. It therefore identifies areas that are more accessible and thus shows the structuring potential of the landscape itself on the movement and routines in landscape. Thus, in addition to more busy areas in the landscape, we should also expect to find non-places and back-areas. Landscape thus structures the pattern of accessibility on given time scales. By varying the time budget we can explore the relation between time and structuring effect of the landscape.

The problem is that it is extremely computationaly intensive. The results also suffer badly from the boundary effect, which means that the values on the edges of study area do not provide real values.

The resulting map can be further analyzed in different ways. One way is by applying the prominence filter (LLOBERA, 2001), which returns the difference of accessibility between a point and other points in the landscape within the arbitrary neighborhood (Figure 6b and 6c). Thus we can observe which parts of the landscape within the neighborhood are more accessible within the allocated space. This makes it possible to explore how landscape is structured into islands of back-water and corridors of movements on different temporal and spatial scales.

All these more or less distinct features, places or locales may be important for the social analysis of landscape. Such places and features can function as "nodes" or as "stations" in time geographic sense, the corridors where daily practices structure and where bundles of activity can occur.

Discussion

Time-geography is not limited to the mere description of courses of events in time and space, but emphasizes the importance of gaining the deeper understanding of fundamental social conditions and processes (LENNTROP, 2004: 223). Simple descriptive tools enable us to study the complex patterns that emerge from agents moving and interacting in landscape. Humans are not simply situated in landscapes; there is a mutual relation, where, on the one hand, the landscape constrains and enables some social practices, and, on the other hand, the landscape is modified and rearranged by its inhabitants (FAHLANDER, 2003: 122-123).

Movement and accessibility are, thus, important parameters in the social analysis of space. The tools we have developed as an extension to the classical time-spatial, such as cumulative potential path area and potential path field, can help us detect "deep" structural properties of interaction in the landscape.

In our opinion these tools are much more robust than straightforward application of least cost paths, the tool often used to study mobility in past landscapes. The main problem with the conventional use of least cost paths is that they are spatially precise, while non-accurate as they are extremely sensitive to the input parameters, such as selection of friction function, algorithm etc., parameters that have an ill-defined relation to the ways people really move in the landscape (MURRIETA FLORES, 2010). The tools we have developed are much less precise, but more accurate, as they focus on the necessary conditions for movement and interaction and reveal the structuring principle on different time and spatial scales. They are also much more difficult to interpret and further work is required to determine what the results really mean in terms of past mobility and interaction.

Time geography also forces us to think about time. Not about universal, abstract time, external to our experience, but lived time, an experiential narrative and a quality of human engagement with the world (GOSDEN, 1994: 1-12). Time arises from the flow of life; it is created through rhythms of bodily involvement with the world. In this perspective, space and time are not separate entities, but come together in each individual life-path. Time and space are unified in practices people weave through time-space. Even if those practices "collapse" into the landscape and become fixed and materialized in places, there is still an inherent "temporality of the landscape" (INGOLD, 1993). The challenge is to properly address this temporality, and develop tools and approaches, which would help us to study it.

Conclusions

The real challenge facing archaeological GIS research lies in the development of concepts, tools, and approaches that can enable us to analyze and understand the complexities of the past human engagements with the world. Time geography can offer a conceptual and methodological framework for conducting accessibility constraint analyses that can be implemented within GIS.

The time geography emphasizes the significance of the material world and its constraints. Time geographical approach outlines the necessary but not the sufficient conditions for human interaction. Thus it provides an approach rather than full theory and requires the utilization of other knowledge and theoretical frameworks. We see this at its this major strength, as it does not come loaded with theoretical baggage, but can be employed as an analytical tool within many different theoretical approaches towards past landscapes.

We have presented the use of cost-surfaces to implement the time geographical concepts, especially the time-space prim and its derivates, cumulative potential path areas and potential path fields. The tools should not be understood as mere descriptive devices, but means for deeper understanding of social processes in a material world. It allows us to see how interaction, communication, and access is made possible or constrained by the material world.

By focusing on the human interactions provided by time and space it allows us to approach the landscape, as an agent of interaction between people. Time spatial framework can help us to understand the limits time and space imposes in the interaction between people and help us reveal a deeper logic of social processes in land-scape. Tools described here can tell us about possibilities and nothing more. They do not offer spatially precise, but non-accurate results. The difficult task of figuring out what happened within those possibilities is left to the interpretative skills of archaeologists.

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