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Geology and inquiry-based learning. The case of sliding rocks

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ABSTRACT

This paper is a proposal to develop inquiry-based learning (IBL) as a methodological approach to learn science. I outline the characteristics of this methodology, which is based on an initial challenge that has not a unique answer. Here we have a complete experience to carry out IBL in a geological case study. Starting with the question presented by the teacher (the mysterious sliding rocks phenomenon in Death Valley), a) students must individually produce hypotheses about the cause of the movement, b) interpret data, previously prepared by the teacher, c) discuss in small group and, finally, d) give an answer. This experience can be extended with modelling and scientific communication activities, as proposed by the author. The experience was performed with 17-year-old students. During the performance, data analysed were collected, showing that IBL allows the development of some scientific skills that discursive methods obstruct or difficult, such as the formulation of multiple hypotheses, the selection of required data and group discussion.


KEYWORDS

Geology; inquiry based learning; sliding rocks

Inquiry-based learning and Geology are a good match

In Spain, secondary school students have a subject called Biology and Geology. Most of the teachers who teach this subject are biologists, and they often relegate Geology content to the background. This paper is a promotion of Geology. It is an invitation to use the contents of Geology to learn science. And learning science is not doing science (Hodson, 2014; Osborne, 2009, 2019). When I refer to learning science, I mean the understanding of a body of knowledge beyond doubt and the development of scientific skills that will enable students to understand the world around them somewhat better, and to provide answers to the challenges they face. In this proposal it is not intended that students do science, neither by creating new knowledge nor by reproducing exactly what scientists do to generate it. We are not waiting for the real answer, we are looking at the making of the answer. Doing science and Learning science are different fields that are related and often overlap, but that teachers must distinguish

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for the sake of our students. So, in this introduction I will try to argue why Geology can help us learn science through IBL methodology. Not from the exclusion of other scientific disciplines, but as a promotion of Geology.

Inquiry-based learning (IBL) is an ideal learning methodology for situations in which the aim is to establish a relationship between variables that explains a phenomenon or observation of nature (Domènech-Casal, 2023; Pedaste et al., 2015). The literature is extensive in attempting to define this methodology (Llewellyn, 2005; National Research Council, 2000; Nilson, 2010; Pedaste et al., 2015; Prince & Felder, 2006, 2007), but in this paper I will not enter this discussion and accept the definition of Capps, Shemwell, and Young (2016) as the closest to my own conception of IBL. These authors, based on National Research Council (2000), National Research Council (2012) and NGSS Lead States (2013), included in their definition seven dimensions that characterise this methodology. The seven dimensions are: asking questions, interpreting data, explaining evidence, communicating, investigating, arguing, and modelling. Their analysis only considered five dimensions, however, because it was impossible for them to discriminate between interpreting and investigating data, and between explaining and arguing evidence. Other researchers offer a variety of rubrics to evaluate the level of inquiry of any activity (Anthony & Person-Pandil, 2001; Buck, Bretz, & Towns, 2008; Fitzgerald and Byers, 2002; Llewellyn, 2013; Marshall, Horton, Smart, & Llewellyn, 2008; National Research Council, 2000; Oppong-Nuako, Shore, Saunders-Stewart, & Gyles, 2015).

I take from Nilson (2010) two important considerations to understand the proposal I am presenting. On the one hand, inquiry can provide a development or stimulus to students' abilities to work with multiple perspectives on a problem, and the uncertainty that arises when choosing among possible solutions. On the other hand, students must have sufficient guidance and scaffolding during the inquiry process, which in many cases relies on a large amount of documentation translated by the teacher from the more specialised scientific language into a format closer to the learner's own. I use the concept of scaffolding to refer to a learning methodology that allows us to build knowledge based on the relationships established between simpler and more easily understandable elements. The teacher prepares and presents the information sequentially in a motivating way to the students, in the form of a challenge, so that the progress towards more complex productions becomes evident. Therefore, a good question, with possible alternative or compatible answers, and a well-constructed scaffolding are prerequisites for meaningful inquiry based learning for students.

Geology is a discipline with great potential to work on inquiry. Since Chamberlin (1890, reprinted in 1965) and his method of multiple working hypotheses, many authors have been describing Geology as a field characterised by uncertainty, because many of the problems it must solve are poorly reproducible in time and space (Ault, 1998, 2014; Bond, Philo, & Shipton, 2011; Frodeman, 1995; Markley, 2010; Wilson, Bond, & Shipley, 2019). Frodeman (1995) clearly states this difference with other sciences such as physics or chemistry, where variables can usually be isolated, and hypotheses can be made to determine if an answer is correct. In many geological problems, the isolation of a variable is not an easy task, and this leads to the need to test the collected data with more than one alternative. Although uncertainty is a feature of all sciences, in the geosciences it is the standard rather than the special case (Wilson, Bond, & Shipley, 2019; Bond, Philo, and Shipton 2011) exemplify the type of problem

geologists are used to confront, often due to the limitation in the resolution and spatial distribution of data. Rarely, the authors say, geologists can ensure “the right answer” for a collection of data. This fact forces them to reason considering some uncertainty, developing an ability to interpret multiple alternatives before giving an answer. The making of a geological map (Martínez & Colldeforns, 1998), the geophysical prospection of the subsoil (Bond, Philo, & Shipton, 2011), the palaeoecological interpretation of an outcrop (Shroat-Lewis & Hage, 2021) or the location of a landfill/stone quarry (Luzón, Sirvent, & Soria, 1998) are problems where the data collected can be compatible with more than one alternative, and the geologist must interpret them to make the most correct decision.

Materials and methods

In this section I will explain a) the case study and data collection to support the scaffolding (supplementary material), b) the methodology for collecting the data that was analysed (see templates in supplementary material) and c) how to extend the experience described.

The sliding rocks. A case of inquiry brought to the classroom

The proposed activity is based on a geological phenomenon observed in different locations on the earth’s surface, but practically unknown to secondary school students (at least in Spain). This feature intensifies the inquiry work the students must carry out, and that is little or not at all mediated by the knowledge they have about the case. Even if students had some prior information about the case, we should not necessarily dismiss this activity as IBL. It is possible that having prior knowledge of the problem can mean a reduction in the application of inquiry, because a person may prefer to defend known evidence rather than think of new alternatives. This will be discussed later when I compare the two ways of conducting the activity.

The challenge is based on the observation of the displacement of rocks of considerable volume and mass in arid and essentially flat terrains, without direct evidence of the causative agent of such movement. They have been called *sliding rocks*. The paradigmatic case, and perhaps the most studied, is in the Death Valley, California, but the phenomenon has been studied in other locations, including some in Spain (Sanz-Montero & Rodríguez-Aranda, 2013).

The author of this paper reviewed the literature and prepared, based on it, a set of individual sheets with information on each of the variables that these references suggest as influencing or causing the rocks displacement. Thus, there are clues (See supplementary online materials for the following data, named as Figure X-SM) about the site topography (Google, 2023, Figure 1-SM), hydrography (U.S. Geological Survey, 2020, Figure 2-SM), lithology (Miller, 2005, Figure 3-SM; McAllister, 1956, Figure 4SM), biodiversity (CCSD, 2023 Figure 5SM; Sanz-Montero & Rodríguez-Aranda, 2013) meteorology, including wind, rainfall and temperature (Dirks, 2023, Figure 6SM; Norris et al., 2014, Figure 7SM; Lorenz, Jackson, Barnes, Spitale, Radebaugh & Baines, 2011, Figures 8SM and 9SM). Some cards were added even though they were not explicitly cited in the bibliography consulted. It was the case for volcanism (Miller,

2005; Smithsonian Institution, 2023, Figure 10SM), tides and coastal processes (Google, 2023, Figure 11 SM), seismicity (Patton, 2023; USTrave, 2023, Figure 12--SM left; UCERF3, 2023, Figure 12SM left; UCERF3, 2023, Figure 12–SM-right) and glaciation, indicating that there is no current phenomenon related to glaciation in the place where the marks are observed.

The IBL experience

The students who performed the activity were enrolled in an Earth and Environmental Sciences course of first year of Baccalaureate (16-17 years old). They had attended some lessons on external geodynamics (approximately 40 hours) that included content on external geological agents (sea, rivers and streams waters, wind, glaciers, and ground-water) under an energetic and lithological perspective that leads to the generation of dynamic landforms. Fifteen of them were encouraged to solve a case presented by the teacher of the subject (in supplementary online materials, Student sheet). Basically, the teacher offered them an aerial image of Racetrack Playa (without mentioning the name) and three pictures of sliding rocks with an indication of the geographical orientation of the marks. A short introduction by the teacher said that some hikers had come to a plain and found these marks on the ground. The challenge question was *how have these rocks moved?* The teacher and four other classmates with no additional background to the problem were responsible for observing and facilitating the performance of the activity. These four collaborators were trained by the teacher in a very simple way, and each was responsible for three students. The one hour performance, which took place in a covered space with access to an outdoor garden, was divided into four timed phases (Table 1) which were communicated to the participants.

In the first phase (ten minutes), the students were informed of the problem to be solved and were asked to write down individually the possible causes or hypotheses that could explain the observation. Meanwhile, the five observers were writing down the moment when the hypotheses of the three students under their supervision were written (in supplementary online materials, Observer sheet).

In a second phase (five minutes), the students, who participated actively, were required to write down what kind of data they would need to test their hypotheses. Five minutes later, the observers would provide these data in the form of photocopies with the clues that the teacher had prepared beforehand, according to a code established by him (in supplementary online materials, Observer sheet)

In the third phase (forty minutes or until the end of session), the three students under the supervision of each observer formed a group to discuss which hypotheses

Table 1. Timing for the activity. What is expected to do for students and observers.

PHASE	TIMING (minutes)	Students	Observers
1	10	Context and question. Writing hypotheses.	Number of different hypotheses for minute and student.
2	5	Collecting data.	Asking for data needed and give it to students.
3	40	Data interpretation and discussion. Working in groups.	How students discussed different hypotheses (nothing, little, much).
4	5	Final explanation and decisionmaking.	How student make their final decision.

were the most plausible to explain the observed phenomenon. During this third phase, the observers wrote down which hypotheses were most discussed by the group. During discussions, each time a group drafted a hypothesis, the observer indicated what time they had done so and whether they continued to discuss to improve, change, or supplement the initial hypothesis.

In the fourth and final phase (five minutes at the end of session), the members of each group and the observers were asked to explain how the group had made the decision on their final answer(s) to explain the observation.

Enhancing the experience

In the following session, the development of the experience and the explanations made by each group were discussed. New questions were asked to test the explanations and only those explanations that were not supported by an accurate analysis of the data were questioned. The teacher showed the video and pictures (in supplementary online materials, Video V1SM, Figures 13SM and 14SM) modelling rock movement according to the hypothesis of rocks surrounded by an ice shelf and moved by wind (Kletetschka et al., 2013; Lorenz, Jackson, Barnes, Spitale, & Keller, 2011). The modelling work was carried out only by the teacher, but it could be part of the activity with a few more sessions available. It could be part of the modelling and communication skills, or even be a new inquiry activity that initiates another cycle of inquiry (Pedaste et al., 2015), since students should relate the movement with other parameters such as the density and shape of the rocks, the ice surface necessary to move them, wind intensity, and acquire technological knowledge about scaling in modelling. Other solutions proposed by students could be also modelled.

Data analysis

All students wrote more than one hypothesis. The mode was four and five hypotheses, and the range was between two and ten. 54 out of 71 hypotheses collected (76%) were written in the first five minutes. Afterwards, production dropped significantly, although in the last minute, three hypotheses were still written (Figure 1).

The hypotheses written by the students mostly fell within the range foreseen by literature, but there was also room for surprise. Let us comment on a few examples:

- *They are grains of sand that have been trapped by an obstacle.*
- *They are rocks that were already there, and the sand has made these tracks because grains of sand could not reach through these obstacles.*

These explanations call into question even the wording of the question asked by the teacher. There is no doubt that it is an alternative explanation that makes us wonder whether the question should be reformulated. The student who wrote these sentences thinks that the wind moves particles of sand that cannot pass through an obstacle (a rock). The result is a trail of grains of sand that can pass on both sides of the rock and a deficit of sand grains just behind the rock.

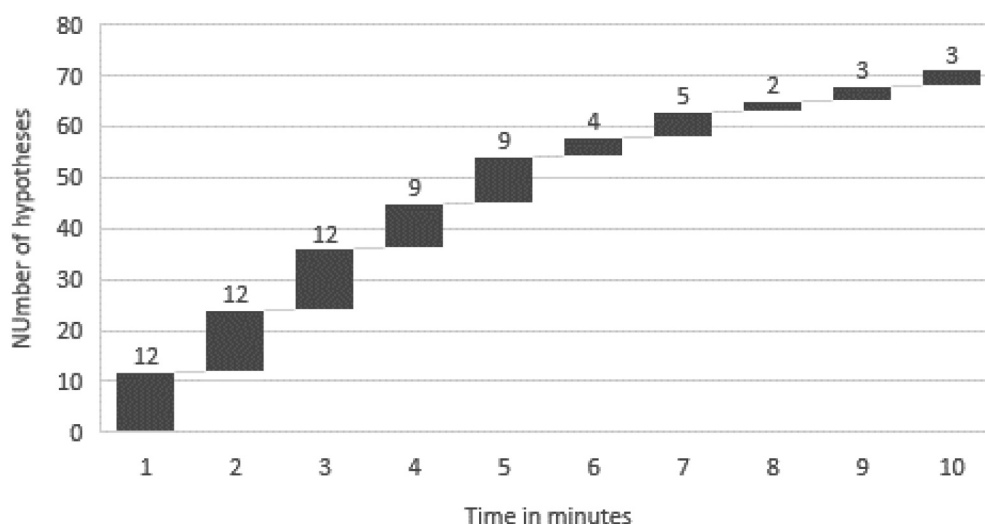


Figure 1. Number of hypotheses written by students (N=15) for minute.

- *They are meteorites.*
- *They may be under the effect of magnetism, so rocks attract or repel each other.*
- *Maybe to the north there is a body with a lot of magnetism that attracts them.*
- *Maybe to the north there is a sinking terrain (author's note: subsidence) and the rocks fall towards it.*

These explanations provide alternatives that do not appear in the literature, nor had they occurred to the teacher. When it was pointed out to the students that no data were available on these alternatives, they continued doing the activity with the rest of the data collected, but we may need to take this into consideration in the future (Hussein, Mickus, & Serpa, 2012 for magnetism, for example).

No student requested all the data that the teacher had prepared. The most required data or “clues” appear in the graph (Figure 2), where all the groups started the second phase with information on “Wind” and “Lithology”. Part of the students requested data that had not been foreseen (shape, size and weight of the rocks, time of travel, location). Although two students wrote hypotheses where they considered magnetism as a possible cause of movement, one of them only requested data on “Lithology” of rocks while the other did not even request them.

During the discussion, no group discussed the possibility that tides explained the observation, exceptionally about glaciation and very little about volcanism or biodiversity. In contrast, all groups discussed a lot about the possibility of wind as a cause of rock sliding and a little less about lithology. Most groups also discussed quite a bit about topography and seismicity (even though two of them with no data available).

The final explanations of the five groups were as follows. Perhaps we need to rethink the scaffold because the diversity of explanatory proposals was surprisingly high, which may be a feature of IBL, but informs us that some step may be missing to discriminate proposals compatible with the data. However, these alternatives generate new questions for further research (Pedaste et al., 2015), discussions or discounts in another class session.

Requested information

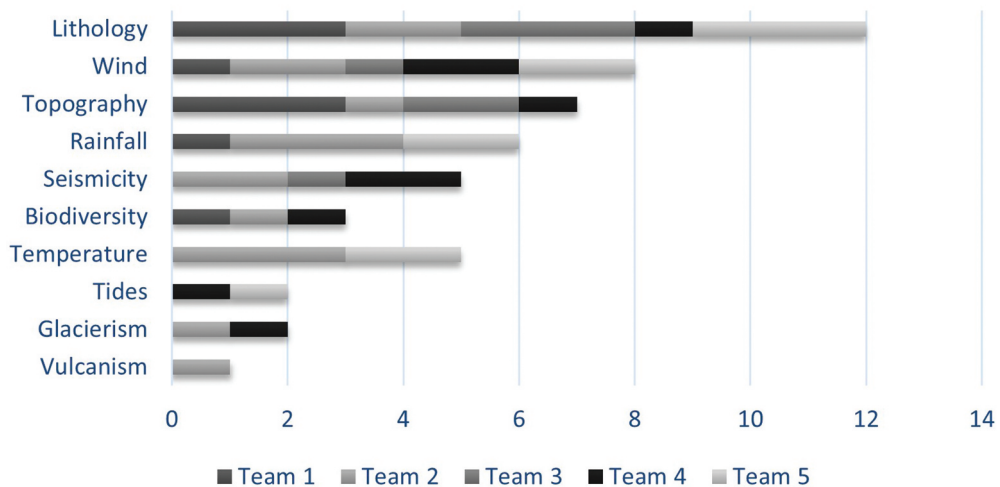


Figure 2. Requested information. We can observe the number of students who asked for some kind of clue and the clues available to each team for discussion.

- *The plain is a salt flat. The rocks break off from the mountains surrounding the salt flat and act as obstacles to the wind, creating these tracks. Rocks do not move. They draw a track (author's note: of fine grained sediment).*
- *A nearby volcano erupted and released pyroclasts. An earthquake has generated a landslide and the rocks have been dragged along the ground.*
- *Torrential waters have come from south to north. We understand that there is water because of the cracks in the ground. The rocks found on the surface come from the multiple and frequent landslides that have occurred in the area because there is a lot of seismicity, evidenced by faults and volcanic and magmatic rocks. The track left by the rock is because they have been moved by torrential waters that have subsequently infiltrated due to the permeability of the soil.*
- *1)The rocks are blown away by the wind that forces them towards the centre. The climate is dry. If the weather is dry, there will be an elevated temperature, therefore, wind will occur. 2) Every 30 years there are earthquakes that give instability to the mountain and cause the material to detach and fall by the force of gravity. 3) Smaller animals want to protect themselves from their predators. Being an arid terrain, they can only hide behind the rocks and move with them.*
- *Here we discard ice because the temperature in the area never falls below 2 °C (author's note: 275,15 K) and vegetation because it is an arid area. Knowing this and that the floor of the lake is salty (it is a salt pan) and that the rock is alluvium (the area is a Quaternary alluvial plain), we believe that the cause of this movement has been rain and wind when they have been coordinated. The wind direction has been NW and has caused the rain to go in that direction making the ground very slippery (being soluble and flat) moving the rock after a few years. By the slope and the force of gravity the rock would have fallen in a landslide in the southern area of the valley.*

It is interesting to note that some group proposed a hypothesis where two variables were combined (wind and rain) to explain the displacement, overcoming the mental barrier of one cause-one-effect.

Regarding how the group decision to explain the phenomenon was carried out, the groups mainly discount some hypotheses and ordered (ranking) the rest, to finally reach a consensus on the answer. In one case, it was preferred to vote on the selected solutions and the majoritarian one was presented. In one group, the authority of a student was highlighted as a trigger for the decision.

Discussion

I can state that the activity I have presented can be considered as an example of an activity that follows the IBL methodology. If we follow the rubrics of Buck, Bretz, and Towns (2008) and Marshall, Horton, Smart, and Llewellyn (2008), the activity reaches the highest levels they have considered.

Thanks to the sheets prepared by the teacher, a good scaffolding was built to progress in the inquiry. The sheets facilitated the selection of possible solutions that were coherent with the data offered, while removing incompatible hypotheses. In this sense, doubts, and possibilities that neither the author nor the literature had seriously considered also appeared, suggesting that new data could be added in future performances of the activity. The fact that most of the answers considered the wind as an essential factor reflects that the inquiry was manageable by the students, but the fact that no group discussed the possibility of ice and wind may mean that the scaffolding was not well defined, that it would be necessary to introduce some content related to ice in the theoretical classes, or that inquiry is characterised precisely by not closing more ways than necessary. Initially it was decided not to show images with more than one displaced rock so as not to show the relationship with the wind too easy, but perhaps presenting the context with an image where several rocks are displaced in the same direction can generate enough connections to opt for a wind+ice hypotheses. I remember, however, that a group made a proposal considering the action of two variables such as wind and stream water, thus skipping the usual consideration of one cause-one effect and having a more complex vision of nature.

Although IBL allows for a large number of working hypotheses, it does not facilitate the consideration of some hypotheses by students, either due to lack of knowledge or experience, or due to the absence of a multidisciplinary perspective. This could be the case of the bacterial mats (Rodríguez-Aranda & Sanz-Montero, 2016; Sanz-Montero & Rodríguez-Aranda, 2013) or other biofilms that could reduce friction and facilitate the displacement of rocks. This is an observation that some students have been able to make when crossing a small stream with slippery pebbles or on the coastline, but which turns out to be very specialised knowledge, and not very geology related for them. We also need to work on this interdisciplinary approach with our pupils. In fact, some of them have thought about the geology related salts to show that a reduction in friction facilitates the movement of any object.

Scaffolding also refers to the opportunities we give students to confront their knowledge with the data obtained. The working group phase facilitates this. Students can compare their ideas with those of the other members, either in the same sense or in

Table 2. Number of hypotheses that could be discussed by a team compared to the higher number of hypotheses provided by a single student to the team.

Team	Maximum individual	Maximum Team
1	4	5
2	6	9
3	2	3
4	3	7
5	4	5

a new sense. In this activity all groups were able to discuss more hypotheses than any of their members had proposed individually (Table 2). In some small groups, however, the most critical aspects of the problem may not be explored, so a discussion phase with the whole class group is needed (Svanteson, 2021).

In the evaluation of the activity, it is necessary to consider the solutions that are compatible with the data and those that are not, and why they are not (Osborne, 2009). Surely, someone could show us a video with his or her pet pushing a rock in his/her backyard, but he or she should explain why his pet does not leave its footprints following the track, and how the movement of so many rocks in the same direction can be explained. In relation to compatible solutions, it is interesting for students to think about what kind of data they would require to decide the best options, scientifically speaking. What would they do if they could be part of a research team at Racetrack Playa? For example, in Norris et al. (2014), the monitoring of movement with GPS sensors embedded in some rocks is already mentioned.

I have already mentioned that a good extension of the activity would be to model some of the solutions compatible with the rock movement based on the data available to students. Modelling with parameters such as wind, stream water, slope, microbial or algal mats, crystallised surface salts, or a combination of some of these would be a good extension of the activity or the beginning of another inquiry activity. Llewellyn (2013) and Pedaste et al. (2015) talk about the inquiry cycle as a powerful methodology for building learnings. The discussion of the case can also be completed with videos such as the one by Rodríguez-Aranda (2021) at https://youtu.be/M8_mPc_f0Ko in which he explains (from minute 12 onwards) the influence of microbial mats on the displacement of rocks in playa lakes in Lillo, Spain.

A shorter version of the activity, without previous theoretical lessons, has been carried out during the last three master's courses for preservice secondary school teachers of Biology and Geology. On the first occasion and faced with the same challenge or question as secondary school students, it was decided to give each group of three students information on one of the parameters that were considered as possible causes. This information was discussed within each group and, subsequently, one member of each group was asked to leave the classroom, while the others remained in the laboratory. These representatives of each group were entering the laboratory one by one to publicly expose an explanation for the movement of the rocks. What was observed at the end of all the presentations and caused a great surprise, not because it was unexpected but because it was conclusive, was that each group, and therefore its representative, had circumscribed their respective explanations to the parameter of what they have received data from the teacher. One group was able to give an

explanation based on topography, another based on rainfall, and so on up to five explanations based solely on the information they had. It seems like a person would rather defend the evidence supported by data presented to them than think about the possibility of other alternatives. This is what Wilson, Bond, and Shipley (2019) calls anchoring bias, which affects decision making under uncertainty. This fact should make us think that the inquiry based learning methodology is more than an option, it is a necessity if we are able to design activities that really promote the interpretation of data, discussion, argumentation, good questions or hypotheses, explanation of evidence from the data collected and modelling. All of this with challenges that allow working with uncertainty and discussion of various alternatives. And to find challenges with these characteristics, Geology can be a good field to look for.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributor

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Ethics statement

This study does not require approval from an ethics committee because no personally identifiable information about the participants appears. The participants agreed to have the experience published in an education journal.

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