Sequence 1

Discovering the experiment made by Eratosthenes and trying to reproduce it

Introduction

This sequence is crucial since it corresponds to the beginning of the project which will last all over the year until June the 21rst. It is preferable to follow the steps as suggested hereafter, starting with an experiment at Sun. However, last year the experiment showed that the Sun can disappear from our sky for several months without ever showing even its weakest ray. If after several weeks you have not yet started because of a poor weather, you can reverse the sessions 1 and 3 (experiment in the classroom with electric torches) and come back to the works outside later.

We wish to draw your attention on the importance of the written traces, which constitute one of the great principles of La main à la pâte. We suggest you, for example, to ask every student to keep a science notebook like you would keep a diary. They will all write down what they understood, discovered, what they wonder, the hypotheses they venture to answer the numerous questions they ask themselves as the activities go by. That notebook will also gather the drawings and diagrams related to the experiments they carried out. You will therefore be able to check that the child has understood and to follow his evolution during the year.

Preparatory session (optionnal) : It consists of activities related to the relations between a light source, objects and their shadow cast on a screen. If youthink your students, after reading these experiments, need a preparatory session on these notions, we recommend you to refer to the optionnal sequence about the throwing of shadows and their relation to the light source.

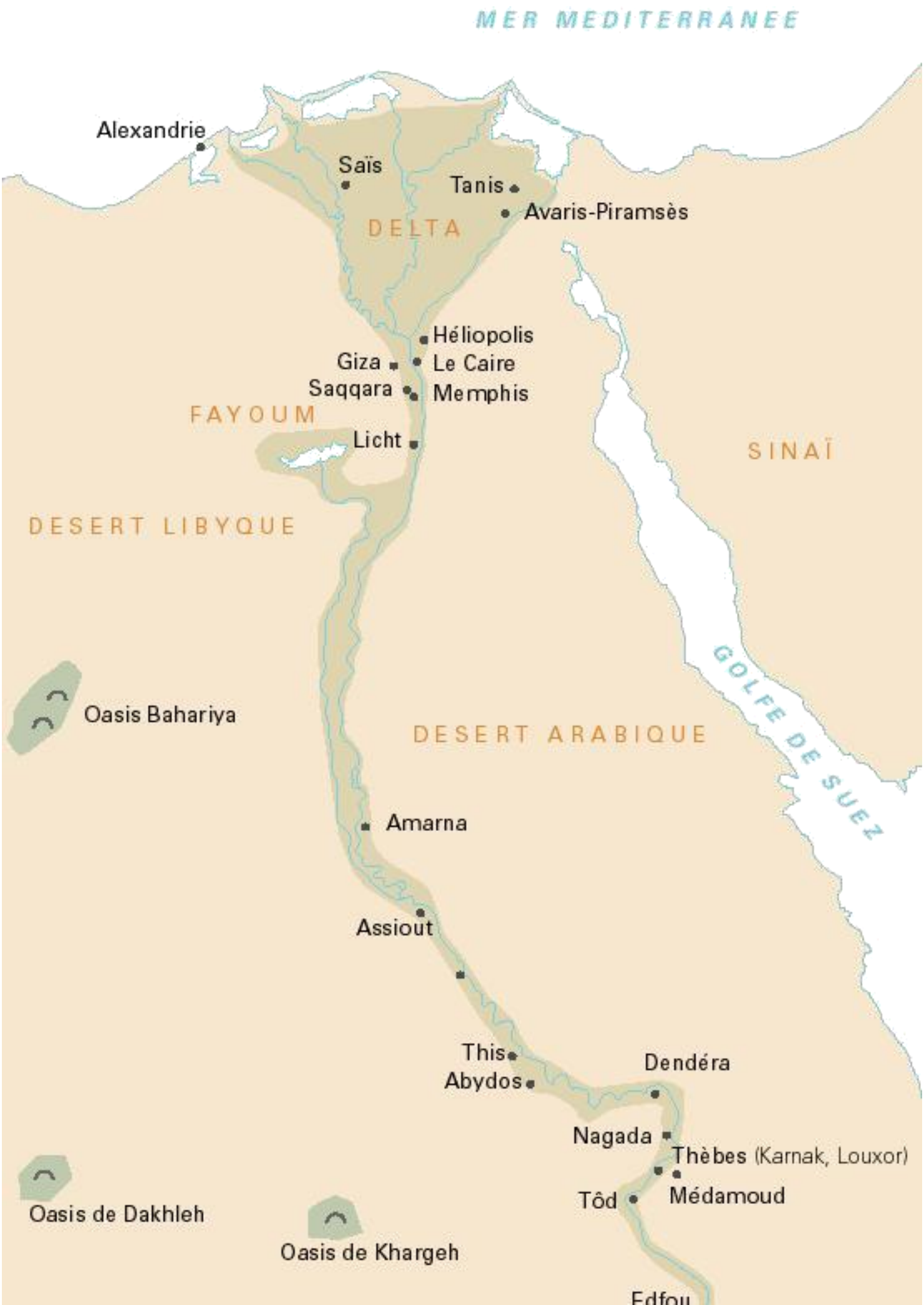
Preliminary : The observations made by Eratosthenes (fictionalized historical text)

Duration : between 15 and 40 minutes of presentation (work on the text)

Once the pupils are divided in groups of four or five, give and make them read the following text at school, accompanied by photocopies of the map of Egypt :

"In Egypt, about 2200 years ago, a papyrus drew attention of a certain Eratosthenes, then Director of the Great Library of Alexandria (a town located on the side of the Mediterranean Sea): it was about a vertical stick which, on the first day of summer (that is to say on June the 21st) and at noon local solar time, did not cast any shadow on the ground (the Sun's rays reach the bottom of a well!). This happened very far from Alexandria, straight to the South, in a town called Syene (now Aswan). However, Eratosthenes noticed from his side that in Alexandria, on June the 21rst also and at the same time, a stick vertically driven in the ground did cast a shadow, even if such a shadow was relatively short. What the hell was this mystery?
We invite you to discover it by yourselves. This will lead you pretty far since, as Eratosthenes showed, the key of this mystery will allow you to measure the circumference of the Earth, nothing less!"

At first, the children carefully mark the keywords of the text: character, places, date, the experiment and its protocol (objects, times, ...). After locating the country on a wall map, ask them to identify on the maps of Egypt the places mentioned in the text. Then explain them that you challenge them to reproduce Eratosthenes' observations inside the sunny schoolyard.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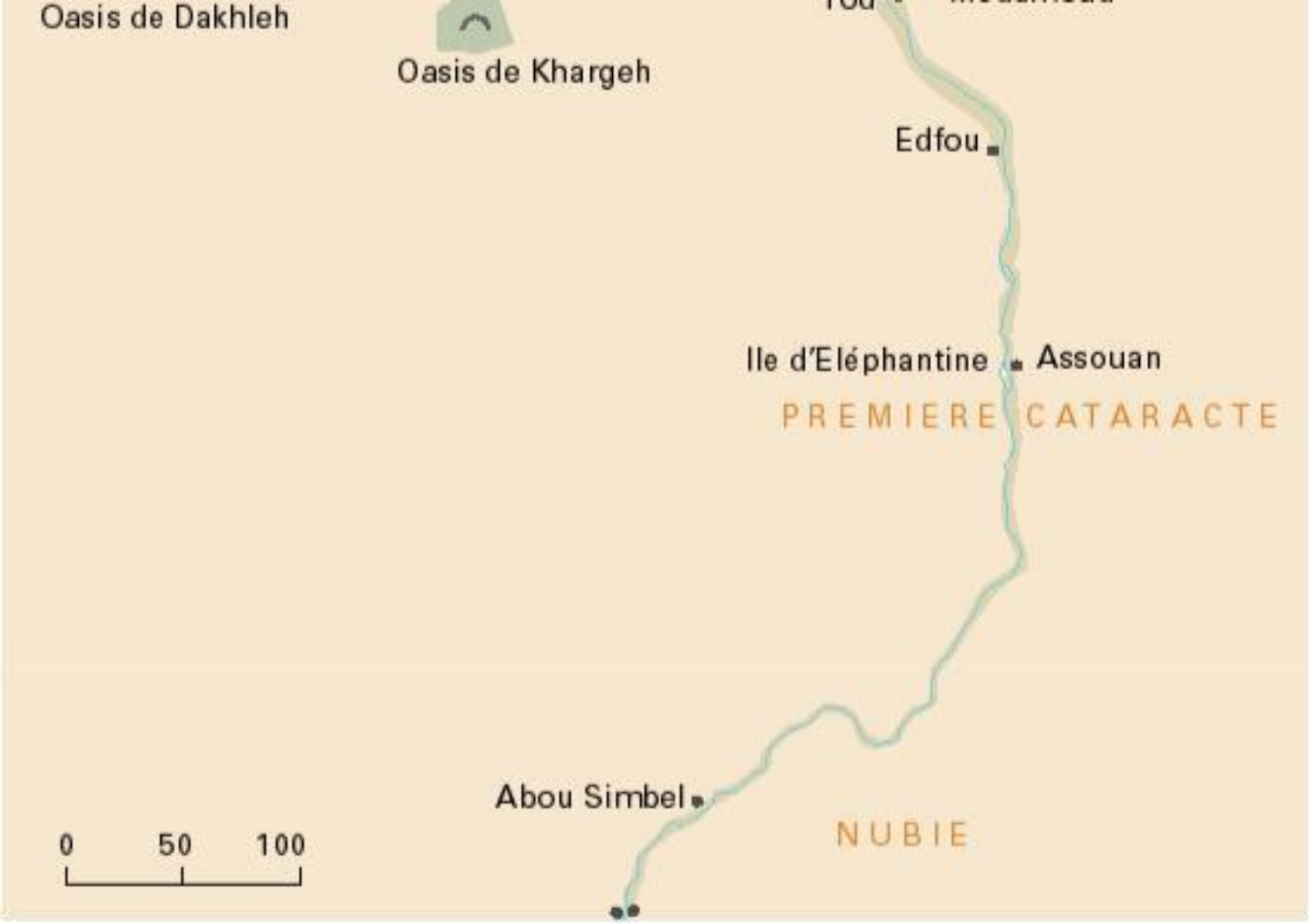

Summary of the sequence:

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1) Reproducing the observations at Sun

Duration : at least to 15 or 20 min for outside experimentation

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Equipment :

For each group of 4/5 pupils :

1 map of Egypt photocopied on one A3 sheet
(or 2 pasted A4 sheets
2 matches or needles or drawing pins
1 pen cap
Adhesive gum, simple or double face adhesive
or paste
Half an hour of sunny weather!

At first they must reproduce the instruments mentionned in the text at a smaller scale. For this, they will represent the sticks by a choice of needles, drawing pins, or matches they will past on the map. Of course, one will have to make sure that these "faked sticks" are really vertically driven in the map. However, do not give them preliminary instructions and let them proceed by trial and error. You just need to mention them that their experiment will have to be absolutely identical to the one described in the text. In Aswan they can either represent a stick or a well using for instance the cap of a pen (perfectly cylindrical) fixed into the sheet.

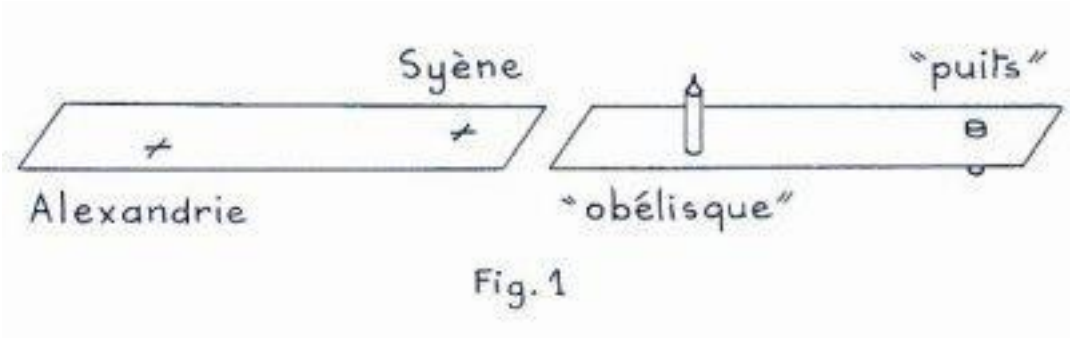

Fig. 1

Ideally you could choose a reporter in each group. He would note the options adopted by the group and the strategy followed (the different trials, the reasons of their possible failures, and the hypotheses they have done). That sheet could be photocopied so as to be used as a first written trace in the science notebooks for the children of each group.

First challenge: Obtain a shadow in Alexandria and simultaneously cancel the shadow in Syene if they have used a stick or make the rays falling in to bottom of the cap-well if they have chosen the second option (if necessary, while the pupils experiment, make them notice that their sticks must not be tilted on the map ...).

The pupils will first see that they must orient the map towards the Sun for the shadow of Syene to disappear (or for the well to be fully enlighted). But then they discover that there isn't a shadow of Alexandria any longer ! Now there is a problem...

After a few minutes of trials and errors, the children will understand that they must curve the map to reproduce the observations made by Eratosthenes, what indicates that the Earth is not flat! Even if its rotundity seems obvious to them, they now have the feeling that they have found arguments in its favour.

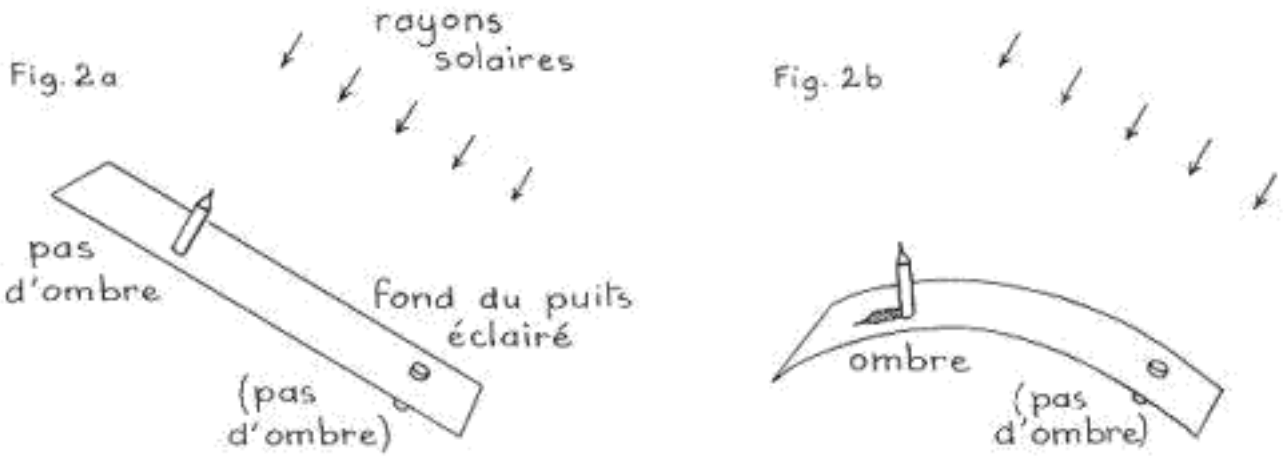

Fig. 2

Second challenge: Vary the length of the shadow in Alexandria without a shadow becoming visible in Syene.

For that purpose, the pupils will have to curve the map more or less, and that way they will see that the length of the shadow of Alexandria depends on the curvature of the map and therefore on that of the Earth.

Third challenge: Vary again the length of the shadow inAlexandria keeping this time the same curvature. The pupils will then have to move away or closerthe stick fixed in Alexandria and will understand that the length of the shadow is also linked to the distance between the towns.

During every challenge, each reporter should write down all the ideas and discoveries on their sheet.

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2) Schematization

Note : immediately after so that they do not forget the results!
You can also place here the activiities on the cast of shadows if the manipulations under the sun proved to be problematic for the children to understand. Don't hesitate to have them do again the first experiments before moving on so as to make sure they well memorized and assimilated them. Last, if this activity of schematization appears difficult to you, you may as well invert sessions 2 and 3, and that way you will insist on the manipulations with the lamps before moving on to the drawings.

Duration : Foresee 20 min in the classroom

Equipment :

For each group of 3/5 pupils :
the experiment book with the drawings, notes, and remarks that the reporter has written down during the experiment.

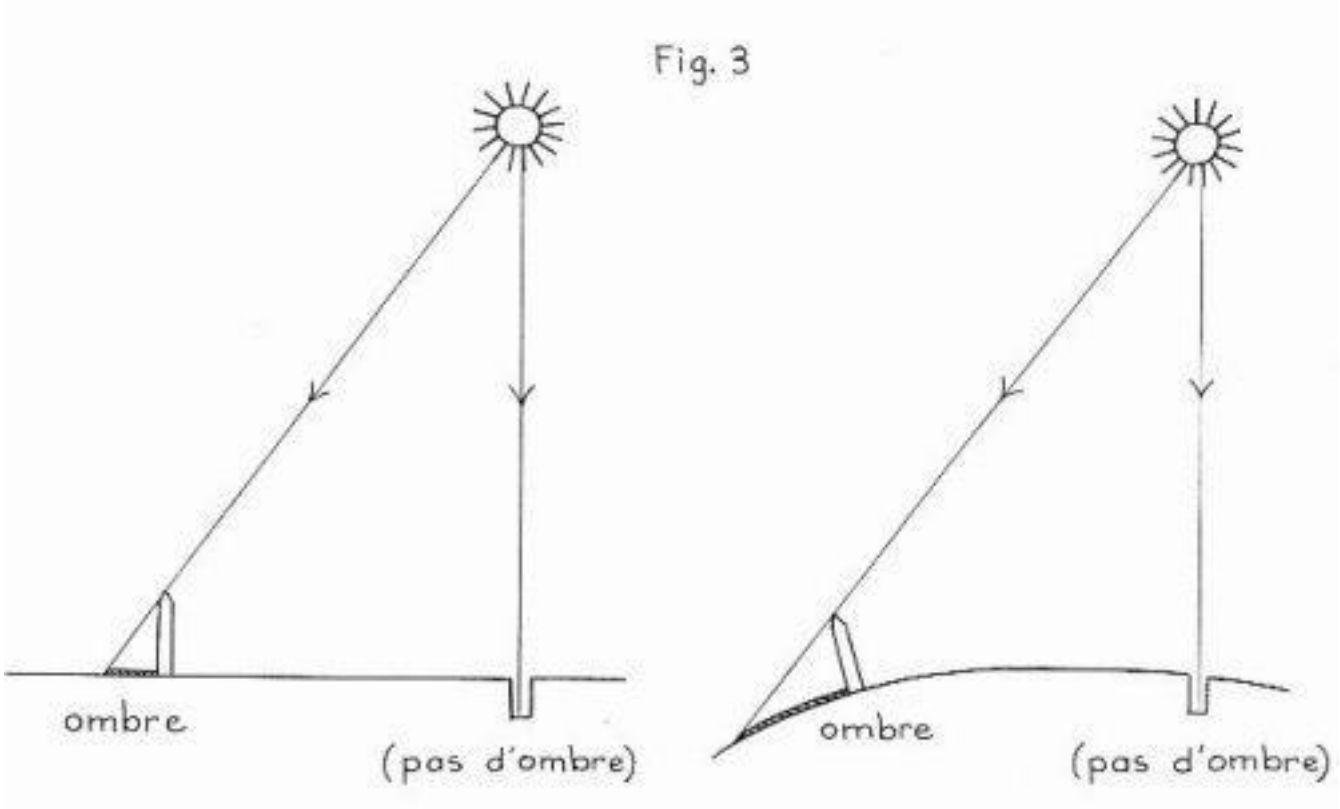
Back in classroom, each group tells the rest of the pupils its thought process, what allows to compare the different approaches followed by the teams.

This experiment has permitted them to show that the Earth is not flat and that the shadow of the sticks varies with the curvature of the terrestrial surface and the distance between the two cities.

Now ask everyone to carry out two drawings of the "experiment in the sunshine"with a representation of the two sticks (or the stick and the well) and the map in profile:
- the first one with a flat Earth: no shadow in Alexandria nor in Syene,
- the second one more conclusive with a curved terrestrial surface and a shadow in Alexandria

Tell them that the Sun's rays must clearly appear on their schemes and that they must be drawn with a rule. If this leads to questions or doubts in the class, you can refer to the optional activities on the propagation of light (see separated slip). Most of the pupils will draw the Sun on their sheet with divergent rays. Seize the opportunity to start the discussion with the pupils on the right way of drawing the Sun's rays. Indeed in this case the children will have to draw a shadow in both places, what does not correspond to what they have observed since there was no shadow in Alexandria when the map was flat (see figure).

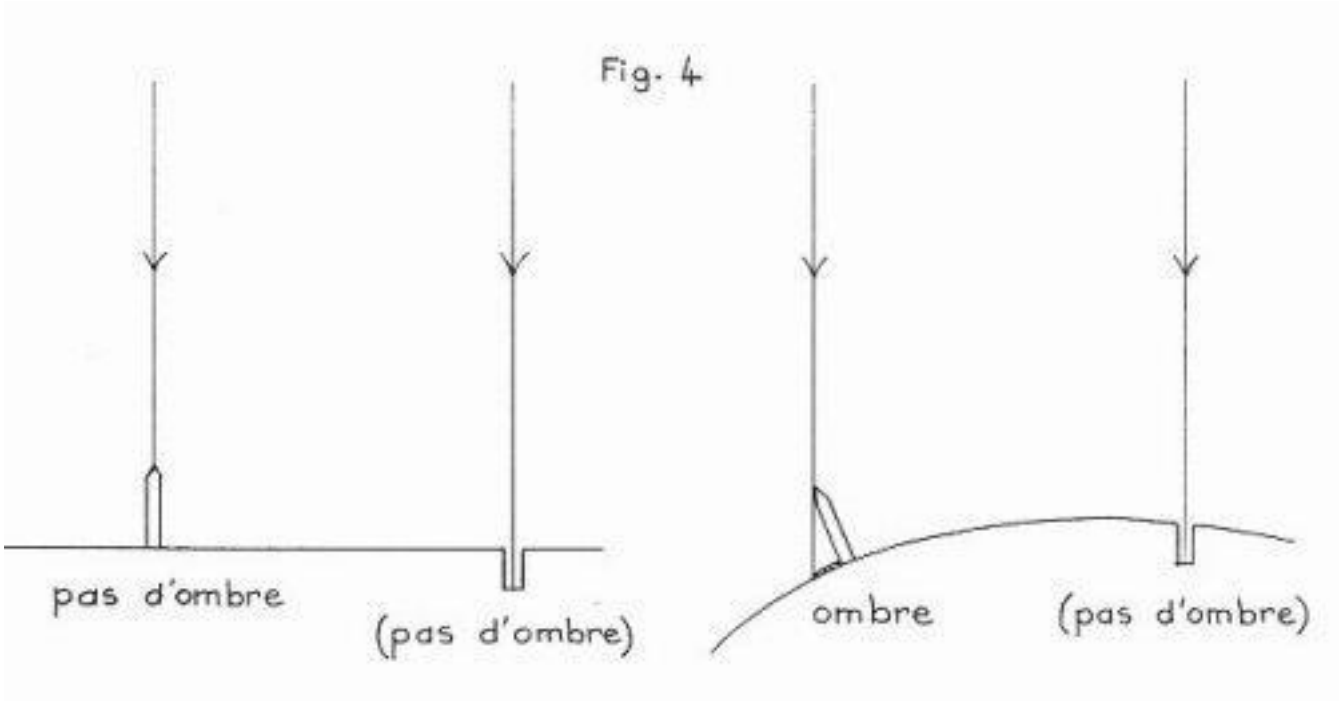
Fig. 3



New challenge : "Look for how to draw the ray falling on the obelisk in Alexandria so that no shadow

appears any longer." One of the children will quickly answer that one has to right the ray until it is in the extension of the obelisk. Then what do they remark looking at the two rays of Sun? Both have the same direction and the gap between them remains constant. Here is what we call parallel rays. They have probably heard this word already.

Then, on the previous two figures, they draw in color the two parallel rays. They find again the observations performed at Sun with a shadow in Alexandria when the map is curved and no shadow in Aswan (the rays fall in the bottom of the well).



But are the rays of the Sun really parallel? How to be sure about this? One should go outside again to be convinced.

If you still have 15 minutes of sunny weather, you can end the session with the activity described further down under the caption "Verification in situ of the parallelism of the solar rays". You can also choose to use it as an introduction for the next session.

Finally, if you still have some time left, you can ask the children to draw the last experiments when they had to curve the map more or less, the sticks keeping the same separation and next conversely when at a given curvature they were varying the separation between the two sticks. You can for instance prepare figures on which the children will only have to trace the two solar rays (perfectly parallel now) and to draw the shadows. Hence you will be able to quickly check that each child has completely understood the experiments performed at Sun. Treasure the drawings and send us the best ones!

Fig. 5

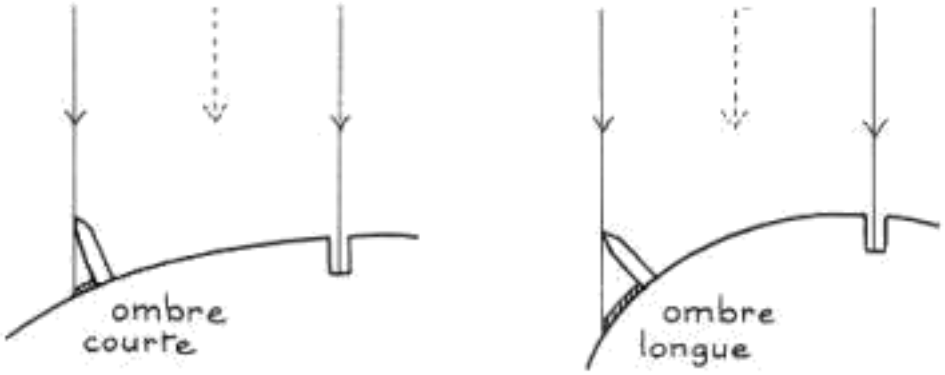


Fig. 5 a
courbure différente
même distance entre les lieux

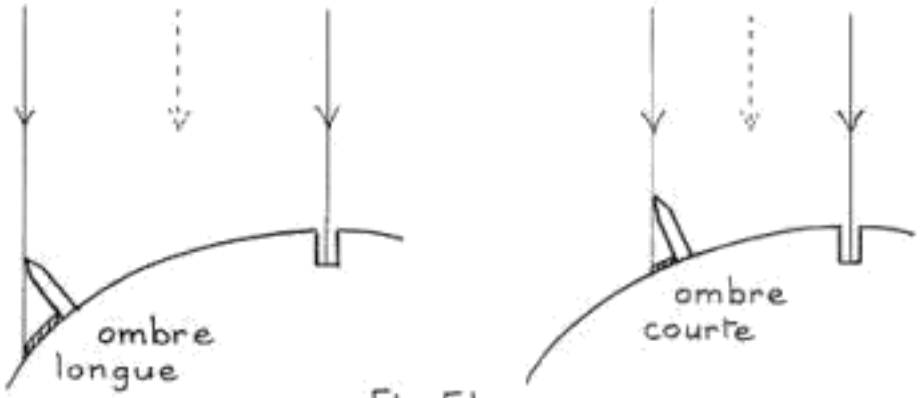


Fig. 5b
même courbure
distance différente

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3) Modeling in the classroom with electric torches

This simulation will allow the children to be confronted this time to the effects of divergent rays of lights. They will then discover how to have them evolve to a progressive "parallelism".

Duration : 30 to 45 min.

Location : Dark place, classroom and then outside

Equipment :

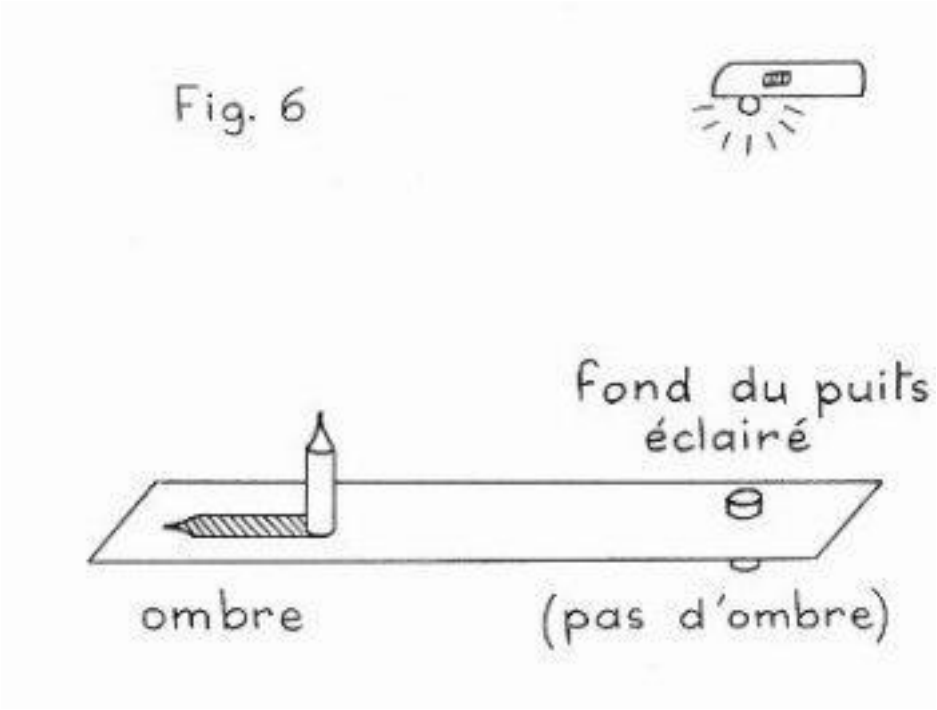
For each group of 3/5 pupils :

One torch, if possible putting away the reflector to improve the cleanness of the shadows
The map of Egypt and tyhe two sticks (or the pen cap)
Then for the following experiment:
3 drawing pins, not too small.
One sheet of squared paper.

This time the aim is to re-do the observations performed by Eratosthenes but with an electric torch instead of the Sun. You can also start the project with this session is the weather is really poor. Like during the first session, you will fix in a Bristol card or on a photocopy of the map of Egypt a stick or a pencil at the location of the two cities. You can also use the cap of a pen to represent the well in Aswan or any other object proposed by your pupils (see picture 1).

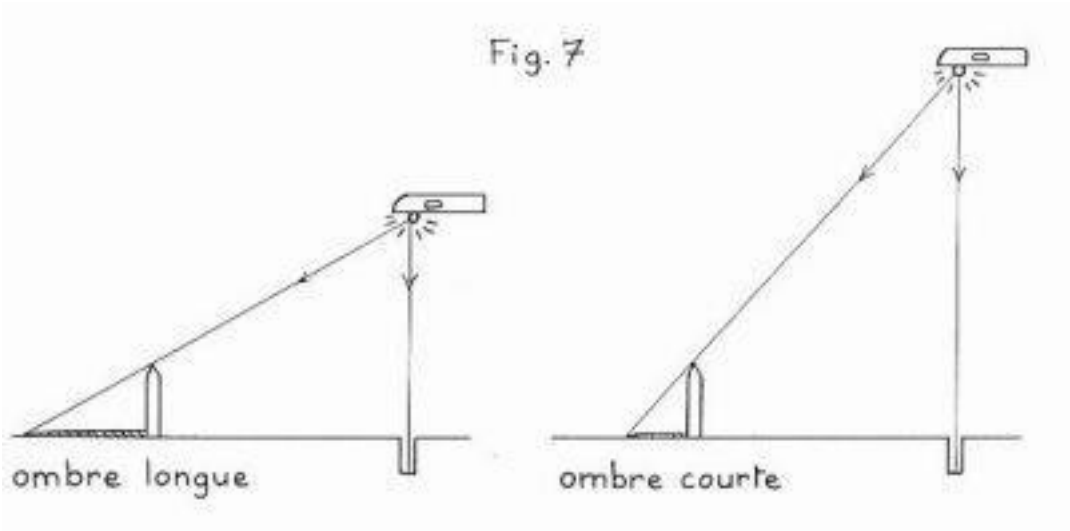
The challenge is the following: The challenge is the same: find again the observations lead by Eratosthenes. To do so, one will have to place the electric torch so that it enlights the bottom of the well (or that it does not cast any shadow in Aswan. By the way you can check that this is equivalent by putting the pen in its cap once the torch is correctly set). They will quickly curve the map as they have done outside, hence checking what our Greek scientist could see. But let us come back to the experiment with the flat map. What happens then?

When the map is flat the children observe that the pen in Alexandria does own a shadow. Exactly like in the first drawing they had done when the rays of the Sun were not parallel! This does not match at all what they have seen outside at Sun. But it then implies that the rays of the torch are not parallel...



New challenge : how to place the lamp so that the shadow of the pen disappears? After several wronfg trials one of the experimenters notes that by raising the lamp above the map, while keeping it completely above the cap in Aswan, the shadow of the pen decreases in Alexandria. If the lamp is brought closer, the shadow increases conversely. "What if one raises the torch until the ceiling, one could probably make the shadow completely disappearing?!". Then they try to move away the torch as far as possible from the map, then understanding that the origin of the light must stand very far away from the map so that its rays arrive totally parallel. What if it was the same for the Sun?

Schématisation de la simulation : From this experiment the students will prove with two sketches the link between the length of the shadow and the height of the light source: they may use a photocopy prepared by the teacher on which they will have to draw two lamps and twopairs of rays.



To be totally convinced of the parallelism of the rays of the Sun, you can end the session with the following activity or remind it to the pupils if they have done it already.

Photo : Huguette Farges, Compiègne

Verification in situ : Verification of the parallelism of the solar rays reaching the surface of our planet

The children observe that the lines of the square paper are really parallel. Then one has to check that the shadows of objects put all side by side on the sheet do follow the lines of the paper and hence are also parallel. This will prove that the rays which form these shadows are parallel themselves.

What happens if you use an electric torch instead of the Sun? The shadows diverge but they come closer to the lines of the grid if one moves the lamp away from the paper. Conclusion: the Sun is really far away from the Earth, so far that its rays reach us perfectly parallel! It is so far that one should better not to draw it on the sketches if one wants to represent its rays!

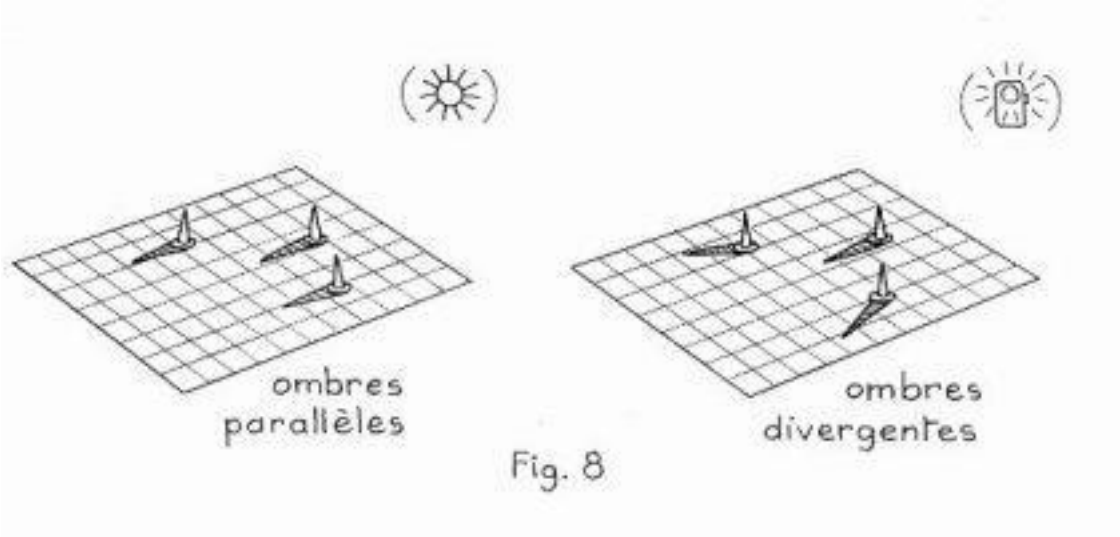


Fig. 8

You can extend this session with the optional activities on the notion of parallelism.

Then don't hesitate to redo the experiment proposed at the beginning of this sequence leading tothe rediscovery of the curvature of the Earth and allowing the children to find again the observations made by Erathostenes. It will allow you to check that every one of them has understood the experiment under the Sun.

Then you will be able to recapitulate with the pupils on a large wall pannel the schemes of the observations made by Eratosthenes with the two hypotheses on the Earth's shape, by drawing absolutely parallel Sun's rays this time so that you can conclude that the terrestrial surface is in fact curved.

NB : Maybe some will raise as an objection the fact that they already knew that the Earth was round! Thanks to this experiment, they have not proven that the Earth is round but rather that its surface is curved and not flat. Seize the opportunity to review the signs that allowed to assume that the Earth was round (at the time of Eratosthenes): navigators perched on the top of their main mast are the first to perceive the distant coastline; observers on top of a cliff have a longer view of ships moving towards the horizon than observers on the beach; the pole star is not at the same height above the horizon in Greece as in Egypt; finally during eclipses of the Moon, the shadow of the Earth projected onto the Moon shows a circular section. If some of the pupils have already observed the sky by night, you can evoke the sky mapping and the fact that some constellations (group of stars creating a figure, like the Great Bear) can only be observed in the Northern or Southern Hemisphere, the sky

varies when one is moving on the surface of the Earth! The position of the polar star above the horizon varies als owhen one is moving on a North/South trajectory.

Complement : To extend this work, you can add a bibliographical research on Eratosthenes, the Great Library of Alexandria, Egypt and its fascinating history that the children will have to carry out for instance in groups, at home or in the classroom, with books or Internet. There is no lack of interesting topics .