Civically engaged to ensure that an earthquake is not a social issue

Introduction

Title

Civically engaged to ensure that an earthquake is not a social issue!

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Summary of the scenario

In this learning situation, students will explore the science and data science behind earthquakes through a multidisciplinary approach that integrates geography, biology and geology, mathematics and statistics, and language. Over the scenario of 15 sessions, students will investigate what an earthquake is, how and why it occurs, how its magnitude is measured, and where earthquakes commonly happen around the world. They will also study historical data on some of the most intense earthquakes in recorded history and the historical data of the earthquakes in the region where the school is located and evaluate how scientists use data science to monitor and attempt to predict seismic activity.
As students gather and interpret data from real seismic events and historical records, they will be challenged to evaluate whether earthquakes pose a realistic threat to their own community. This exploration will culminate in the creation of a journalistic article titled *"Are you afraid of an earthquake in Puerto Real, yes or no?".* In this final product, students will use the data, graphs, and insights they've developed during the learning process to take a stance, present evidence, and communicate their findings to a broader audience in a compelling and informative way.

Age of the students

15 and 16 years old. Grade 10.

‘Data Science Content in STEAM for Civic Engagement and Social Justice from the Early Years’

Subjects and topics

Biology, Mathematics and Digitalization

Real-life questions

1. What causes an earthquake to happen, and how do tectonic plates contribute to seismic activity?
2. How do scientists measure the strength of an earthquake, and what is the Moment Magnitude Scale?
3. What global regions are most vulnerable to earthquakes, and why do these areas experience higher seismic activity?
4. How can we predict the occurrence of an earthquake, and why is prediction so challenging?
5. How can we use real-time data from sources such as IGN to track earthquakes?
6. How do historical earthquake events, such as those in Japan or Chile, impact our understanding of seismic risks?
7. What risks do residents of Puerto Real face in the event of a major earthquake, and how likely is it to occur in this region?
8. How can we visually represent earthquake data to communicate findings effectively?
9. What ethical considerations must we take into account when communicating earthquake data to the public?
10. Based on your research, should people in Puerto Real be afraid of earthquakes? Why or why not?

Objectives the scenario

1. Biology and geology:
    a. Define what an earthquake is and how it forms
    b. Identify the tectonic processes responsible for seismic activity.
    c. Understand how earthquake magnitude is measured using the Moment Magnitude Scale (Mw) from the original Richter scale.
2. Geographical Context:
    a. Locate global seismic zones and identify regions most prone to earthquakes.
    b. Assess the local risk of earthquakes in Puerto Real and the surrounding area.
3. Historical Inquiry:
    a. Research major earthquakes in world history based on their magnitude and damage.

    b. Analyze the causes and consequences of these earthquakes.
4. Data Literacy:
    a. Use the online IGN earthquake database to track and visualize the last 10 years activity in the zone.
    b. Create graphs and visuals to represent earthquake frequency, magnitude and locations.
    c. Analice possible associations between the different variables that are related to earthquakes.
    d. Deduce generative models for informal inference reasoning about the variability of the data and looking for patterns.
    e. Construct machine learning predictive models of decision trees to establish the warrants and qualifiers of the earthquakes occurrence.
    f. Interpret real seismic data and historical events.
5. Communication and Journalism:
    a. Develop a journalist article based on collected data and visual representations.
    b. Present findings on earthquake risks in Puerto Real based on the machine learning predictive models of decision trees established.
    c. Take a stance in the articles' title question, *"Are you afraid of an earthquake in Puerto Real, yes or no?",* and support it with evidence.

Skills and competencies

1. Skepticism Toward Data
   Students will learn not to accept data at face value. While analyzing earthquake data (such as magnitude, location, and frequency), they will question:
    - Where did the data come from?
    - How was it collected or measured?
    - What might be missing or misleading?

   This critical stance will help students make more informed and responsible interpretations of data.
2. Willingness to Work with Uncertainty
   Earthquake prediction and risk assessment involve complex variables and incomplete data. Students will experience firsthand that:
    - Data does not always give clear answers.
    - Scientific models (e.g. for earthquake forecasting) have limitations.

   This will encourage comfort with ambiguity and helps them reason probabilistically - an essential disposition in data science.
3. Sense-Making with Data
   Rather than just creating graphs or summarizing statistics, students will:
    - Ask meaningful questions.
    - Use data to develop insights and support conclusions.
    - Combine quantitative evidence with real-world context in their journalist article.

   This reinforces the habit of using data not just for computation, but to understand and explain the phenomena.

4. Argumentation using data
   Students will practice using data as evidence to:
   - Take a position when answering the question of the product, *“Are you afraid of an earthquake in Puerto Real, yes or no?”.*
   - Defend that position in writing with reasoning, evidence, and visuals.

This disposition supports data-based reasoning, helping students communicate complex ideas effectively and responsibly.

5. Curiosity and Motivation to Explore
   Through access to real-world seismic data and tools, students will be encouraged to:
   - Explore patterns and anomalies.
   - Investigate areas of personal or local interest.

   This nurtures a data-exploratory mindset, where students are motivated by discovery, not just correct answers.

6. Ethical Awareness and Responsibility
   When interpreting and sharing data about natural disasters, students will reflect on:
   - The real-world impact of how data is presented (e.g., fears vs preparedness).
   - The importance of accuracy, transparency, and context in communication.

This cultivates a sense of ethical responsibility when working with data that affects public understanding and safety.

Teaching approaches and learning strategies/theories

In this learning situation, the **inquiry-based learning (IBL)** methodology will be introduced as a core approach to foster student engagement and scientific understanding through active investigation and problem-solving. The inquiry process begins by presenting students with real-world questions, such as "Should people in Puerto Real be afraid of an earthquake?" This open-ended question encourages students to engage in critical thinking and data analysis as they investigate seismic activity both locallyIGN, using digital tools to create graphs and identify patterns in earthquake occurrence and magnitude. By working in groups and conducting independent research, students will practice formulating hypotheses, testing predictions, and synthesizing data to support their conclusions. The final product—a journalistic article—serves as a platform for students to communicate their findings, using evidence to argue for or against the perceived earthquake risk in Puerto Real. This approach not only develops scientific inquiry skills, such as data interpretation, but also nurtures critical dispositions, including skepticism, curiosity, and ethical responsibility, as students learn to evaluate and communicate complex scientific data effectively. Through inquiry-based learning, students are empowered to explore, question, and critically assess information, deepening both their understanding of earthquakes and their broader analytical skills.

Relating the national curriculum with the DataScEd4CiEn scenario

1. Scientific Competence

- **Understanding Natural Phenomena:** Students will grasp how earthquakes form, how they are measured (Moment Magnitude Scale), and how tectonic plates influence seismic activity.

- **Data Analysis and Interpretation:** Students will work with real seismic data to identify patterns, compare magnitudes, and understand global and regional earthquake risks.

- **Use of Scientific Language:** They will develop the ability to explain complex concepts using correct scientific terminology in both written and oral communication.

2. Digital Competence

- **Information Search and Verification:** Students will learn to navigate online databases (e.g., USGS, EMSC) to extract relevant earthquake data.

- **Data Visualization:** They will use digital tools (e.g., spreadsheets, graphing software) to create meaningful graphs and charts that support their conclusions.

- **Critical Use of Technology:** They will evaluate sources and verify the reliability of the information gathered online.

3. Communication in the Mother Tongue (Language Competence)

- **Writing for a Purpose and Audience:** Through the final journalistic article, students will practice structured, purposeful writing that informs and persuades.

- **Oral Communication:** Classroom discussions, debates, and presentations will help students express scientific findings clearly and coherently.

- **Textual Analysis and Production:** Students will analyze examples of journalistic writing and apply similar techniques to structure their own articles.

4. Social and Civic Competence

- **Awareness of Local and Global Issues:** Students will explore how natural disasters like earthquakes affect communities worldwide and assess the risk to their own town (Puerto Real).

- **Civic Responsibility and Preparedness:** The unit fosters reflection on how communities can prepare for natural hazards and encourages proactive, informed citizenship.

5. Learning to Learn

- **Research Skills:** Students will plan and conduct investigations, synthesize diverse sources of information, and draw conclusions from evidence.
- **Self-Regulation and Autonomy:** Through the process of writing the final article, students will manage time, make decisions, and revise work independently.
- **Collaboration and Reflection:** Working in groups and participating in feedback sessions will help students assess their own learning and improve through peer input.

6. Critical Thinking and Problem Solving

- **Evaluation of Risk:** Students will use scientific reasoning and data to evaluate whether an earthquake poses a real threat to their region.
- **Decision-Making Based on Evidence:** They will take a stance in their article (yes or no) and justify it with facts, figures, and reasoned argumentation.

Educational Scenario planification

Description of the lesson plan: name of the activity, subject, procedures, time, resources. Complete the next table and include the links to the Annexes section with the detailed description of the activity.

Lesson plan

Name of the activity	Procedures	Time/Annex
Lesson 1: Motivation to the project		
STEAM subject: biology and geology	Why does the Earth have layers?	Annex B1 60’

	Through 2 listening activities, students have to try to remember as many things as possible regarding the layers of the Earth.	
Expected learning outcomes	The layers of the Earth, discontinuities and characteristics.	

STEAM subject: biology and geology	How do you know what is under the Earth's crust? A reading with activities in it to get familiar with the indirect methods to know about the Earth's interior.	Annex B2 60’
Expected learning outcomes	Get familiar with the indirect methods to know about the Earth's interior.	

Lesson 3: Seismic waves		
STEAM subject: biology and geology	Seismic waves Students are in teams, then each team gets separated and students meet in expert groups to analyze the types of seismic waves. Then they will come back to the original teams to put in common the information they have about each type of seismic wave. At home, students have to watch videos to have the next session prepared.	Annex B3 60’
Expected learning outcomes	Types, characteristics of seismic waves	

Lesson 5: Earth's magnetic field, our shield and locating Earthquake epicenter		
STEAM subject	It has 2 parts, at least 2,5 h are needed in this session. In the first part through a reading activity students analyse the characteristics of the Earth's magnetic field and the consequences of a hypothetical weakening of this field. The second part consists in a hands-on activity to locate an earthquake's epicenter.	Annex B5 2.5 h
Expected learning outcomes	The characteristics and importance of the Earth's magnetic field. How epicenters are located.	

STEAM subject	Final test	1 hour
Expected learning outcomes	This test summarizes the knowledge of the geosphere of the 5 previous sessions.	

Lesson 7: Justification		
STEAM subject Mathematics	1. Pre-reading questions. Imagining a strong eathtquake and nswering the question: What do you think that will happen to your neighbourhood? What do you think would be affected most? 2. Reading about the historic and social implications of earthquakes. 3. Post reading questions to analyze which are the social justice consequences of an earthquake.	Annex I 20’
Expected learning outcomes	Think of an earthquake as a major social issue. Reading how an earthquake can be a social justice issue. Research major earthquakes in world history based on their magnitude and damage. Analyze the causes and consequences of these earthquakes.	

Lesson 8: S1 and S2. Recognition of patterns in historic earthquakes		
STEAM subject: Mathematics	1. Watch a video and summarize how historical data can help to predict and prepare for future earthquakes. 2. Think of how many earthquakes have occurred in the Iberian Peninsula in the last ten years. 3. Access the WebPage of the National Geographic Institute and research on the previous question. 4. Access the catalogue of earthquakes from 1370 A.D. to present times and find data corresponding to the last 10 years. 5. Analyzing which variables provide the table of information obtained. 6. Access CODAP with a sample of 5000 cases and perform a data analysis. 7. Analyze the truthiness of the information of a newspaper through an extensive data analysis of official data.	Annex 2 120’

Expected learning outcomes	Use the online IGN earthquake database to track and visualize the last 10 years activity in the zone. Create graphs and visuals to represent earthquake frequency, magnitude and locations. Analice possible associations between the different variables that are related to earthquakes. Deduce generative models for informal inference reasoning about the variability of the data and looking for patterns. Assess the local risk of earthquakes in Puerto Real and the surrounding area.

Lesson 9: S3 and 4. Understanding conditional probability to predict the occurrence of an earthquake in Puerto Real.		
STEAM subject	1. Understanding what is a contingency table and conditional probability. 2. Determine using a contingency table the simple and conditional probabilities of earthquakes with epicenter in Puerto Real. 3. Access to the IGN catalogue of earthquakes and use CODAP arbor decision tree algorithm to perform a predictive modelling analysis considering different variables and construct a contingency table with the information of the decision tree. 4. Conclude with the differences that they can find when working with different samples 5. Analyse the representativeness of the samples to introduce the principles of machine learning. 6. Understanding what population, sample and sampling is by engaging with Edpuzzle: https://edpuzzle.com/assignments/67c5cad0851a1199b5ff31d6/watch	Annex 3 120’
Expected learning outcomes	Construct machine learning predictive models of decision trees to establish the warrants and qualifiers of the earthquakes occurrence. Interpret real seismic data and historical events.	

Lesson 10: S5. Many magnitudes and units of measurement of the magnitude of Earthquake		
STEAM subject	1. With the aim to connect with the biology and geology subject, students are asked: do you know how the magnitude of an earthquake is measured? 2. Reading a text of an official website of the United States Government about the Moment	Annex 4 60’

	Magnitude, Richter scale- what are the different magnitude scales, and why are these so many? 3. Reasoning on the numbers and variables that appear on the equations that model the different scales of magnitude of an earthquake. 4. Introducing the notation of a logarithm. This activity can be a motivation to the introduction of the logarithm meaning, notation or change of base.	
Expected learning outcomes	Understand how earthquake magnitude is measured using the Moment Magnitude Scale (Mw) from the original Richter scale.	

Lesson 11: S6. Graphical representation of the moment magnitude.		
STEAM subject	1. Reading what it means the moment magnitude and other scales. 2. Transforming the equation of the moment in a function in which the independent variable is MO and the dependent variable is MW. 3. Use Geogebra classic to plot the function and analyze its properties. 4. Determine the rate of change and the average rate of change of the seismic moment. 5. Interpret the rate of change and the average rate of change to understand the growth of the function of the moment. 6. Generalize the situation to other logarithmic functions.	Annex 5 60’
Expected learning outcomes	Understand how earthquake magnitude is measured using the Moment Magnitude Scale (Mw) from the original Richter scale.	

Lesson 12: S7. Final product. Write a journalistic article		
STEAM subject	1. Read on which are the hallmarks of journalistic writing. 2. Write a journalistic article based on the data and graphs that you have produced during the learning situation with the title: “Are you afraid of an earthquake in Puerto Real, yes or no? 3. Analyze if your journalistic article accomplishes the principles defined in the	Annex 6 120’

	hallmarks of journalistic writing. 4. Improve the article if necessary.	
Expected learning outcomes	Develop a journalist article based on collected data and visual representations. Present findings on earthquake risks in Puerto Real based on the machine learning predictive models of decision trees established. Take a stance in the articles' title question, *"Are you afraid of an earthquake in Puerto Real, yes or no?",* and support if with evidence	

Timing

Describe for each category the time planned for its implementation

Preparation time: 1 hour

Teaching time planned for each of the STEAM subjects

STEAM Biology and Geology: 7 sesiones of 60 minutes each

STEAM Matemáticas: 5 lessons with a total of 500 minutes

Assessment time:

2 hours one in biology and another one in mathematics.

Teaching resources (materials & technological tools)

Describe the teaching materials and technological tools to be used in the different lessons

Materials

The materials are included in the different annex of the scenario

Online tools

Geogebra: geogebra.org

CODAP: https://codap.concord.org/

Spanish National Geographic Institute: https://www.ign.es/web/ign/portal

Evaluation

Initial assessment

No initial assessment is needed due to the fact that it begins with a session of motivation and evaluation of students preconceptions on the layers of the Earth.

Assessment tools

Describe the tools used for the assessment of:

- Assessment tools in biology and geology:
    - Session 4: Hands-on activity with a slinky.
    - Session 5: Hands-on activity: locating an earthquake's epicenter.
    - Session 6: Final test.
- the students' data science knowledge in civic engagement and social justice in the topic of the scenario that you have planned:
    - The activities produced by the students of lessons 7, 8 and 10.
    - The final product. Write a journalistic article
- students' disposition to learning data science. (Annexes used in the classroom are welcome)
    - The DataScEd4CiEn students' post-survey.

References:

Lee, H. S., Wilkerson, M., Grover, S., Shin, H., & Macrander, C. (2022). *Developing students' data science competencies through exploratory data analysis tasks: A framework and design principles.* Journal of the Learning Sciences, 31(1), 60–101.

Biology and geology annexes:

S1: Why does the Earth have layers?

1. Observe the photo. What's happening? Why?
2. Listen to your teacher and try to fill in the missing information on your photocopy. Do it with the blue pen. S1 SA5 Layers of the earth
3. Share with your teammates what you have and vice versa, fill in the information you didn't get with the black pen.
4. Watch the video and fill in the information you didn't get with the red pen. Why Does The Earth Have Layers?

But… the deepest hole in the Earth is the Kola borehole, its depth is 12,262 m, which is 12 km/6378 km (radius of the Earth), in other words we have just drilled 0.18% of the Earth. So, how the hell do we know about the Earth's interior?

S2: How do you know what is under the Earth's crust?

Despite several ambitious projects to dig all the way through the Earth's crust, it has never been done. However, that hasn't prevented scientists from researching and learning about the internal structure and composition of the Earth. There are other ways to know about the Earth's interior.

1. For example, when a volcano erupts, **rocks coming from the Earth's interior** reach the surface. One of those rocks is **kimberlite**, an igneous rock and a rare variant of peridotite, known for being the main host matrix of diamonds. And a diamond is formed at a depth of 150 km when carbon crystallises. So this is giving us evidence of the composition of the rocks at that depth.
2. In addition, **volcanoes** show us that the material inside the Earth can reach very high temperatures, meaning that there is **a direct relationship between depth and temperature**. Rocks are a very good insulating material (aislante) That is why the Earth's interior is still hot after 4.5 billion years. Which are the sources of the heat?
    a. The remaining heat from the collisions that occurred in the formation of the Earth.
    b. The mantle contains radioactive elements such as uranium and thorium, which undergo fission reactions to transform into lead and release energy.
    c. The outer core is liquid, but it is gradually solidifying and this also releases heat.
    d. Observe the graph. Has the heat supply of radioactive elements always been the same? Which isotopes provided the most heat on the primitive Earth? Why do you think they don't provide as much heat any more?

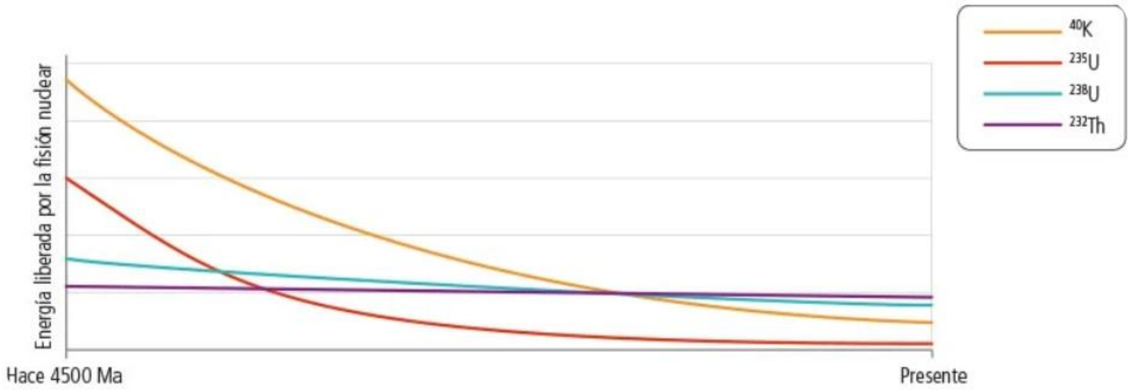


Image: Sm e-book biología y geología 4º de ESO.

3. All the bodies in the Solar System were formed at the same time and they all came from the matter of a nebulae. And we can say that **meteorites** are part of those bodies. There are meteorites **made up of iron and nickel**, they are called siderites, others, chondrites are made up of **silicates** (olivine and pyroxene) like peridotite, this suggests that the **Earth's interior could contain the same materials**.
4. **Density** is a property that can give us evidence about the composition of the Earth's interior.
   a. Calculate the density of the most common rock on the Earth's surface: granite.

Image: Sm e-book biología y geología 4º de ESO.

   b. Observe the table, Which rocks are denser? The ones we have on the surface like granite or the ones we have inside the Earth like chondrite or siderites?

	G	C	Si

	ranite	hondrite	derite
Density (g/cm^3)	¿?	3.3	8.0

c. The Earth's mass is $5.97 \cdot 10^{24}$ kg. Its volume can be calculated by knowing its radius, $V=4/3 \cdot pi \cdot r^3=1{,}08 \cdot 10^{12}$ km^3. Given that, you can calculate the average density: 5.5 g/cm^3. So, if on the surface we have granite with a density of 2.75 g/cm^3 and the average density is 5.5 g/cm^3 …that means that…?

5. **The magnetic field**. The inner core is solid and made up of iron and nickel, in addition it is surrounded by molten metal (the outer core) which has convection currents and electric currents linked with the magnetic field. This field protects us from solar winds (protons, helium nucleus and electrons) which travel at a speed ranging from 300 to 1,200 km/s. Without our magnetic field solar winds would wipe out our atmosphere.

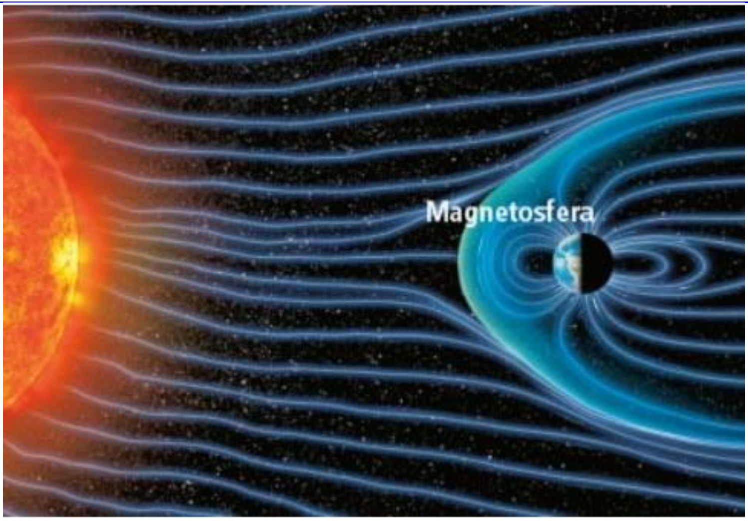
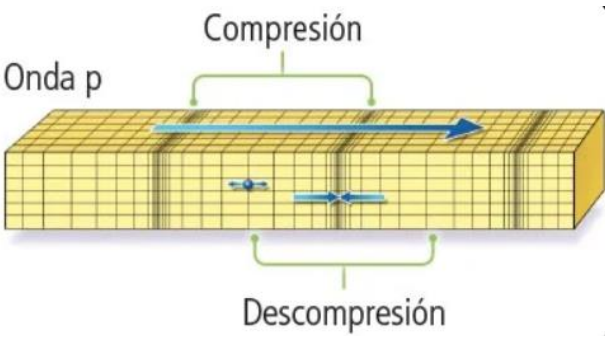


Image: Sm e-book biología y geología 4º de ESO.

6. Seismic waves

Seismic waves generated in earthquakes are the main source of information about the earth's interior. Their speed depends on the material they pass through. There are two types of waves, p-waves and s-waves. The p-waves are transmitted by solids and liquids. S-waves are only transmitted through solids.



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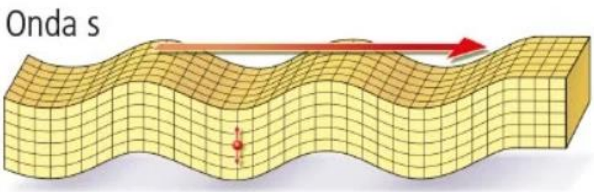


Image: Sm e-book biología y geología 4º de ESO.

An earthquake at point O (seismic focus) is recorded after a period of time at seismic stations A, B, C and D. The image shows the paths of the wave fronts and, in the table below, the distance between the focus and the different stations, as well as the time elapsed before it reaches the stations.

S3: Seismic waves

Cooperative learning: expert groups.

Do you remember something about seismic waves?

Image from: Mezclas coloidales y Efecto Tyndall

Today we're gonna learn more things about seismic waves. Each member of each team will meet with members of other teams to deepen their knowledge of seismic waves.

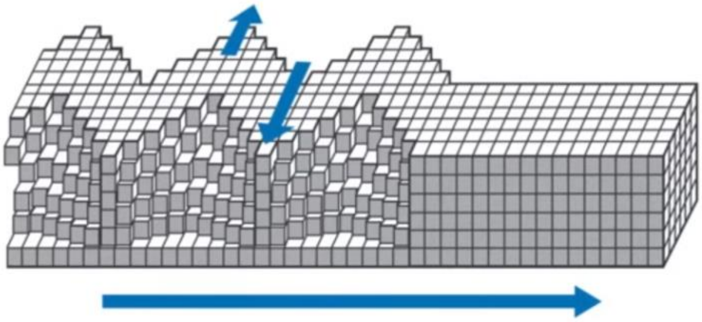
Expert group 1. Surface waves

Seismic waves are vibrations that travel through the Earth, generated by sources such as earthquakes, volcanic activity, or explosions. These waves are classified into two main types based on how they move through the Earth: **body waves** and **surface waves**. Each type has distinct characteristics and behaviour.

1. Surface Waves

Surface waves travel along the Earth's surface and are slower than body waves. They tend to cause the most damage during an earthquake. There are 2 types:

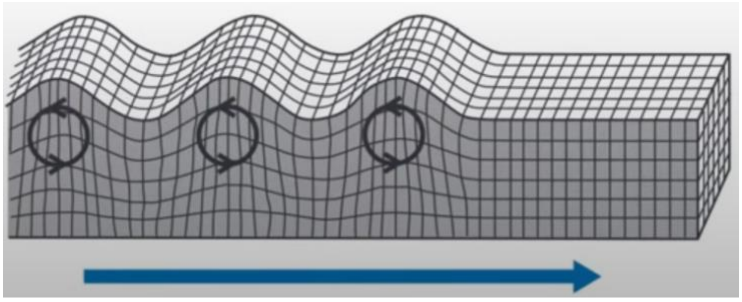
a. Love Waves



Peycheva (2021). Seismic waves propagation: love waves (image adapted from Olivadoti, 2001)

- **Type:** A type of surface wave that moves in a horizontal, side-to-side motion. Like a snake.
- **Speed:** Love waves are faster than Rayleigh waves but slower than body waves.
- **Effect:** They are responsible for causing significant damage due to their horizontal motion and the intense shaking they create at the Earth's surface.

b. Rayleigh Waves



Peycheva (2021). Seismic waves propagation: Rayleigh waves (image adapted from Olivadoti, 2001)

- **Type:** Another type of surface wave that causes a rolling motion, similar to ocean waves. The ground moves both vertically and horizontally in the direction of wave propagation.
- **Speed:** Rayleigh waves are slower than Love waves and typically the slowest of the seismic waves.
- **Effect:** Rayleigh waves often result in vertical ground movement, which can cause extensive damage to buildings, roads, and other structures.

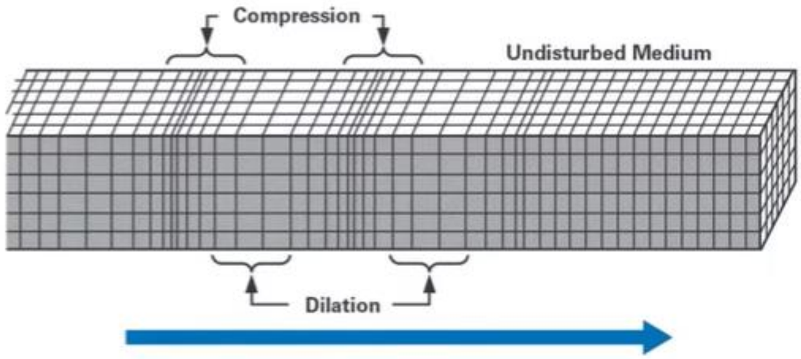
<u>Expert group 2. Body waves, P-waves.</u>

Seismic waves are vibrations that travel through the Earth, generated by sources such as earthquakes, volcanic activity, or explosions. These waves are classified into two main types based on how they move through the Earth: **body waves** and **surface waves**. Each type has distinct characteristics and behaviour.

2. Body Waves

Body waves travel through the Earth's interior and are divided into two subtypes:

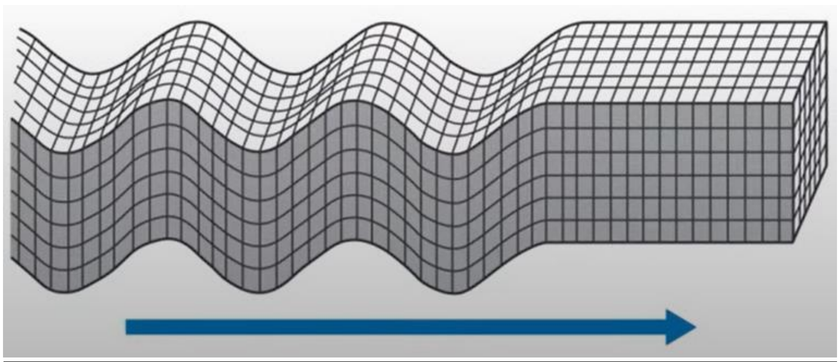
a. Primary Waves (P-waves)



Peycheva (2021). Seismic waves propagation: Primary waves (image adapted from Olivadoti, 2001)

- **Type:** Longitudinal (compressional) waves.
- **Motion:** P-waves move in a back-and-forth motion along the direction of propagation (similar to sound waves).
- **Speed:** They are the fastest seismic waves and are the first to be detected by seismographs.
- **Medium:** P-waves can travel through both solid and liquid.
- **Effect:** Because of their speed, they are the first waves detected in an earthquake, but they typically cause the least damage.

<u>Expert group 3. Body waves, S-waves.</u>



Peycheva (2021). Seismic waves propagation: Secondary waves (image adapted from Olivadoti, 2001)

Seismic waves are vibrations that travel through the Earth, generated by sources such as earthquakes, volcanic activity, or explosions. These waves are classified into two main types based on how they move through the Earth: **body waves** and **surface waves**. Each type has distinct characteristics and behaviour.

2. Body Waves

Body waves travel through the Earth's interior and are divided into two subtypes:

b. Secondary Waves (S-waves)

- **Type:** Transverse (shear) waves.
- **Motion:** S-waves move the ground perpendicular to the direction of wave propagation, causing a side-to-side or up-and-down motion.
- **Speed:** S-waves are slower than P-waves, which is why they arrive second on a seismograph.
- **Medium:** S-waves can only travel through solids and are unable to pass through liquids (e.g., the Earth’s outer core is a liquid).
- **Effect:** S-waves tend to cause more damage than P-waves because of their larger amplitude and the side-to-side shaking.

Summary of Key Differences

Type	Motion	Speed	Medium	Cause of Damage
P-waves	Con	Fas	Sol	Low

	pressional (longitudinal)	test	id & Liquid	damage
S-waves	Shear (transvers	Slower than P-wav	Solid	Moderate damage

	e)	es		
Love Waves	Horizontal (side-to-side) Like a snake	Faster than Rayleigh	Solid surface	High damage
Rayleig	El	Sl	Su	Hi

h Waves	liptical (rolling)	owest	rface	ghdamage

Seismic waves play a critical role in understanding the Earth's internal structure and the behavior of earthquakes.

<u>Expert group 4. Body waves and the Earth's interior.</u>

Seismic waves are vibrations that travel through the Earth, generated by sources such as earthquakes, volcanic activity, or explosions. These waves are classified into two main types based on how they move through the Earth: **body waves** and **surface waves**. Each type has distinct characteristics and behaviour.

How they help us understand the Earth's interior:

1. **Revealing the Earth's Layers**:
    - The way P-waves and S-waves travel through the Earth provides clues about the different layers inside the planet.
        - **Outer core**: Since S-waves cannot travel through liquids, their absence in certain regions of the Earth (such as the shadow zone, which is an area on the Earth's surface where no S-waves are detected) tells us that the outer core is liquid. P-waves can still pass through the outer core, but they are refracted (bent), which helps us understand the density and composition of this layer.

- **Inner core**: P-waves can travel through the inner core (which is solid), and this provides evidence of its solid nature. The travel times and paths of these waves can help determine the composition and size of the inner core.

2. **Determining the Composition and Density**:
   - The speed at which both P-waves and S-waves travel through different layers can tell us about the material's density and elasticity. For instance, slower seismic waves often indicate less dense or more fluid materials, while faster waves suggest denser, more rigid materials.
3. **Creating the Earth's Seismic Model**:
   - By analyzing how P-waves and S-waves travel through the Earth, scientists can create detailed models of the Earth's internal structure, including the thickness and composition of the crust, mantle, outer core, and inner core. This is achieved by studying how seismic waves are refracted, reflected, or absorbed at various boundaries between layers.
4. **Seismic Tomography**:
   - Seismic tomography uses the travel times and paths of seismic waves to produce 3D images of the Earth's interior. This technique has helped reveal complex details about the mantle's convection currents, the distribution of heat, and the dynamics within the Earth's core.

In summary, P-waves and S-waves are fundamental to understanding the Earth's interior. Their behavior as they pass through different materials allows seismologists to infer the composition, state (solid or liquid), and structure of the Earth's layers.

Let's do a little experiment: Demonstrating P and S Seismic Waves

Videos to help you to study:

GCSE Physics - Seismic Waves #75

How earthquakes show us the inside of the Earth

Earthquakes and Seismology in Earth's Interior

At home: Seismic Slinky—An analogy for P & S waves [educational]

S4: Seismic waves experiment.

Hands-on geology activity about **P-waves (Primary waves) and S-waves (Secondary waves)** using a slinky:

Write the title in your notebook: Exploring Earthquake Waves with a Slinky

Vocabulary:

Coil: anillo, muelle.
Shear motion: side-to-side motion.
Hands-on: práctica.

Objectives, students will:

1. Understand the differences between P-waves and S-waves.
2. Learn how seismic waves propagate through Earth.
3. Relate wave motion to real-world geological phenomena.

Materials:

- 1 long slinky per group (preferably metallic for better wave propagation)
- Tape or markers for labeling
- Stopwatch (optional)
- Worksheet with guided questions and diagrams

Activity Steps:

Part 1: Introduction to Seismic Waves

1. **Introduction and key concepts**:
    - Seismic waves are produced by earthquakes and body waves are classified into P-waves (compressional waves) and S-waves (shear waves).
    - **P-waves** are longitudinal and travel faster. Particles move parallel to the wave direction.
    - **S-waves** are transverse and travel slower. Particles move perpendicular to the wave direction.
    - Diagram or animation to show how these waves travel through Earth's layers.
        i. P and S Waves Animation
        ii. Seismic Wave - Javalab

iii. https://ds.iris.edu/seismon/swaves/index.php?lat=-36&lon=-73&depth=19&mag=8.8&title=2010%20Off%20of%20Chile&date=2010-02-27T06:34Z&w_terrain=false&wiki=https%3A%2F%2Fwww.iris.edu%2Fhq%2Fretm%2Fevent%2F962

Part 2: Hands-On Activity

Activity 1: Modelling P-Waves

- Stretch the slinky on a flat surface with two students holding each end.
- One student quickly pushes and pulls their end of the slinky (compress and release) to generate a longitudinal wave.
- Observe:
  - How the wave moves along the slinky.
  - The direction of particle movement compared to wave propagation.
- Answer in your notebook:
  - What happens to the spacing between coils as the wave passes through?

Activity 2: Modelling S-Waves

1. Hold the slinky as before, but this time one student moves their end side-to-side perpendicular to the slinky's length.
2. Observe:
   - How the wave shape changes.
   - The direction of particle movement compared to wave propagation.
3. Answer in your notebook:
   - How is this motion different from P-waves?

Part 3: Comparing P-Waves and S-Waves

1. Generate both wave types one after the other and observe the speed difference:
   - Push-pull the slinky for P-waves.
   - Side-to-side motion for S-waves.
2. Answer in your notebook:
   - Taking into account only the observation made: Which waves seem faster, the p-waves or the s-waves?

- Is that what happens in reality, and why do you think it happens in the model?

Part 4: Conclusions

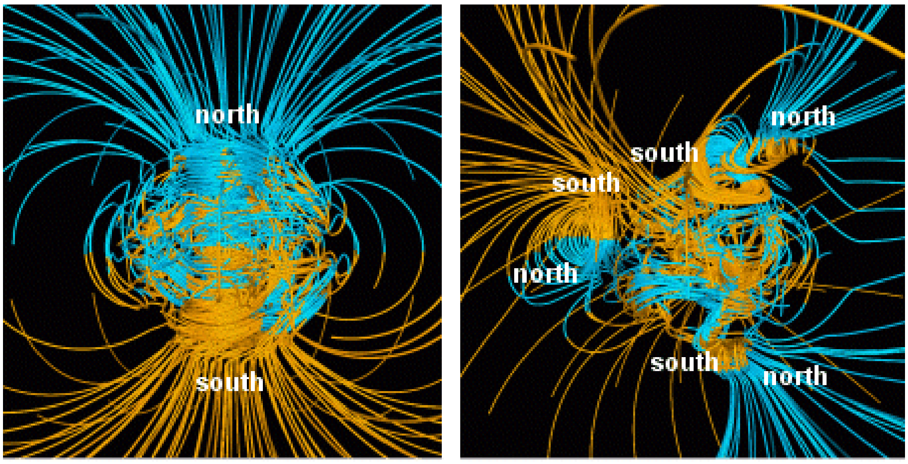
1. Answer in your notebook:

    - Why do P-waves reach seismometers first during an earthquake?
    - Why do S-waves disappear in Earth's outer core?
    - What is the difference between s-waves and p-waves?
    - What happens to the speed of the waves if the density of the material they pass through increases?
    - What happens to p-waves as they propagate through a liquid?
    - Draw and label the particle motion of P-waves and S-waves.
    - Look up what the shadow zone is.

S5: Earth's magnetic field, our shield and locating Earthquake epicenter

Part 1: Earth's magnetic field, our shield

The Earth's magnetic field undergoes reversals over geological timescales, meaning i**t can switch its polarity—north becomes south and vice versa.** This process, known as a geomagnetic reversal, doesn't happen at a regular rate but occurs over periods of thousands to millions of years.

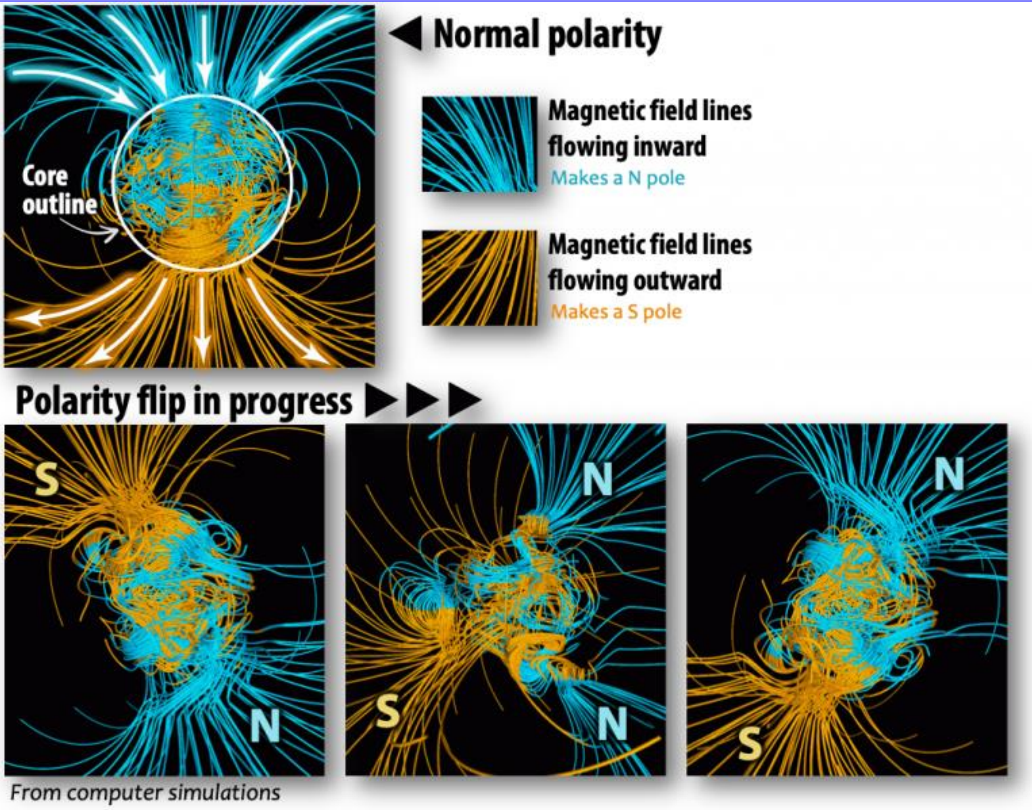


between reversals during a reversal

Image: Glatzmaiers and Roberts (1995). A three-dimensional self-consistent computer simulation of a geomagnetic field reversal

On average, the Earth's **magnetic field reverses every 200,000 to 300,000 years**, although there is considerable variability. For example, the last reversal, the Brunhes-Matuyama reversal, occurred about **780,000 years ago**. The time it takes for a reversal to complete can range from **a few thousand years** to **several tens of thousands of years**.

During the reversal process, the field doesn't simply flip instantly. Instead, it **weakens, becomes disordered**, **and may have multiple poles at different latitudes before stabilizing in the new orientation**. This process happens gradually over time, but there is no precise timeline for each individual reversal.



https://pressbooks.bccampus.ca/physicalgeologyh5p/chapter/3-4-earths-magnetic-field-2/

The next magnetic field reversal, known as a geomagnetic reversal, would have significant but not catastrophic consequences. Here are the main potential consequences:

1. Weakening of the Earth's Magnetic Field

- During a reversal, the Earth's magnetic field will weaken significantly. This might lead to increased vulnerability to solar radiation and cosmic rays. A weaker magnetic field would mean that **more solar and cosmic radiation could reach Earth's surface**.
- The magnetosphere, which shields the Earth from these energetic particles, may not provide its usual level of protection for a period of time. This could potentially increase the risk of radiation exposure for astronauts, aviation at high altitudes, and **possibly even increase cancer risks over long periods of time for people living at higher altitudes or near the poles**.
- The increased exposure to charged particles could disrupt satellites, causing potential damage to **electronic circuits**.
- Increased solar radiation during a magnetic field reversal **could cause more interference with communication systems that rely on radio waves, such as GPS, satellite communication and radio broadcasts.**

- **Effects on animal navigation**. Many animals, such as migratory birds and sea turtles, rely on the Earth's magnetic field for navigation. A reversal could potentially disrupt these processes, although it is unclear how severe this would be. Some species might be able to adapt, but others could face difficulties during their migratory journeys.
- The weakened field might **cause more intense auroras** (northern and southern lights) at latitudes farther from the poles, as solar particles reach deeper into the atmosphere.
- Geomagnetic storms and high-energy particles could **interfere with electronic systems, such as power grids**, and lead to damaging currents in satellites and power lines.

2. Geophysical Changes

- Although a geomagnetic reversal doesn't directly cause volcanic eruptions or earthquakes, the process is thought to be linked with long-term changes in Earth's interior dynamics. The shifting magnetic field might be associated with other deep Earth processes, but there is no direct evidence linking magnetic reversals to surface disasters.

3. Climate Effects (Uncertain)

- There is no conclusive evidence to suggest that geomagnetic reversals cause significant climate change. However, there is some speculation that changes in solar radiation levels, due to variations in the Earth's magnetic protection, could have minor impacts on climate patterns.
- The magnetic field primarily affects solar radiation exposure rather than the Earth’s overall temperature.

Conclusion

The gradual nature of the reversal means that its effects are unlikely to be felt all at once and might not result in significant disruptions on a human timescale. A geomagnetic reversal, while not directly catastrophic, could have lasting effects on technology, animal navigation, and space-based infrastructure. However, the transition would occur over a very long period of time, allowing for adaptation and mitigation efforts. The most immediate concern would likely be the increased exposure to radiation and its impact on sensitive electronics and systems. The reversal is a natural, albeit rare, event in Earth's geological history, and the planet has undergone numerous reversals without any known mass extinctions or irreversible climate shifts associated with them.

Part 2: Hands-on activity: Locating an Earthquake's Epicenter

Hands-on activity: Locating an Earthquake's Epicenter

Scientists use the **time difference between the arrival of P-waves and S-waves** at a seismic station to calculate the distance of the station from the earthquake's epicenter. This method is known as **triangulation**, and it involves the following steps:

1. Understanding P-waves and S-waves:

P-waves (Primary waves) are faster seismic waves and arrive at the seismic station first. **S-waves (Secondary waves)** are slower and arrive after the P-waves.

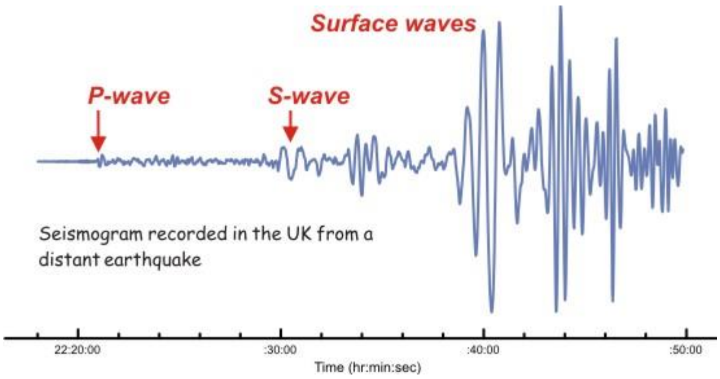


Image: https://earthquakes.bgs.ac.uk/education/eq_guide/eq_booklet_how_we_measure.htm

The difference in **amplitude between S-waves and P-waves** on a seismograph is related to the physical and dynamic properties of these seismic waves. P-waves are longitudinal and type of movement involves less deformation of the medium, resulting in **smaller amplitudes** on the graph whereas S-waves are transverse waves so this kind of motion causes greater deformation in the material, leading to **larger amplitudes** on the seismograph

2. Time Difference and Distance:

The difference in arrival times between P-waves and S-waves (denoted as $\Delta T = TS - TP$) increases with the distance from the earthquake's epicenter. Seismologists use this time difference to estimate how far the earthquake occurred.

A graph named as **travel-time curve** or an equation is used to relate the ΔT to the distance between the seismograph and the epicenter.

3. Determining the Epicenter:

To pinpoint the epicenter:

Measure the time difference (ΔT\Delta T) between the P-wave and S-wave arrivals at a seismic station. Use the travel-time curve to calculate the distance (D) from the seismic station to the epicenter. Determining Epicenter Distance

Repeat this process for at least three seismic stations. Each station determines a circle on a map, with the station at the center and the radius equal to the calculated distance D. The intersection of these circles marks the epicenter's location.

4. Why Three Stations?

Using three stations ensures accurate location, two stations narrow the location to two possible points (where the two circles intersect). Three stations provide a unique intersection point. This triangulation process enables scientists to determine the earthquake's epicenter with high precision.

Exercise: Locating an Earthquake's Epicenter

Find the epicenter of this earthquake that has been registered in 3 different seismic stations:

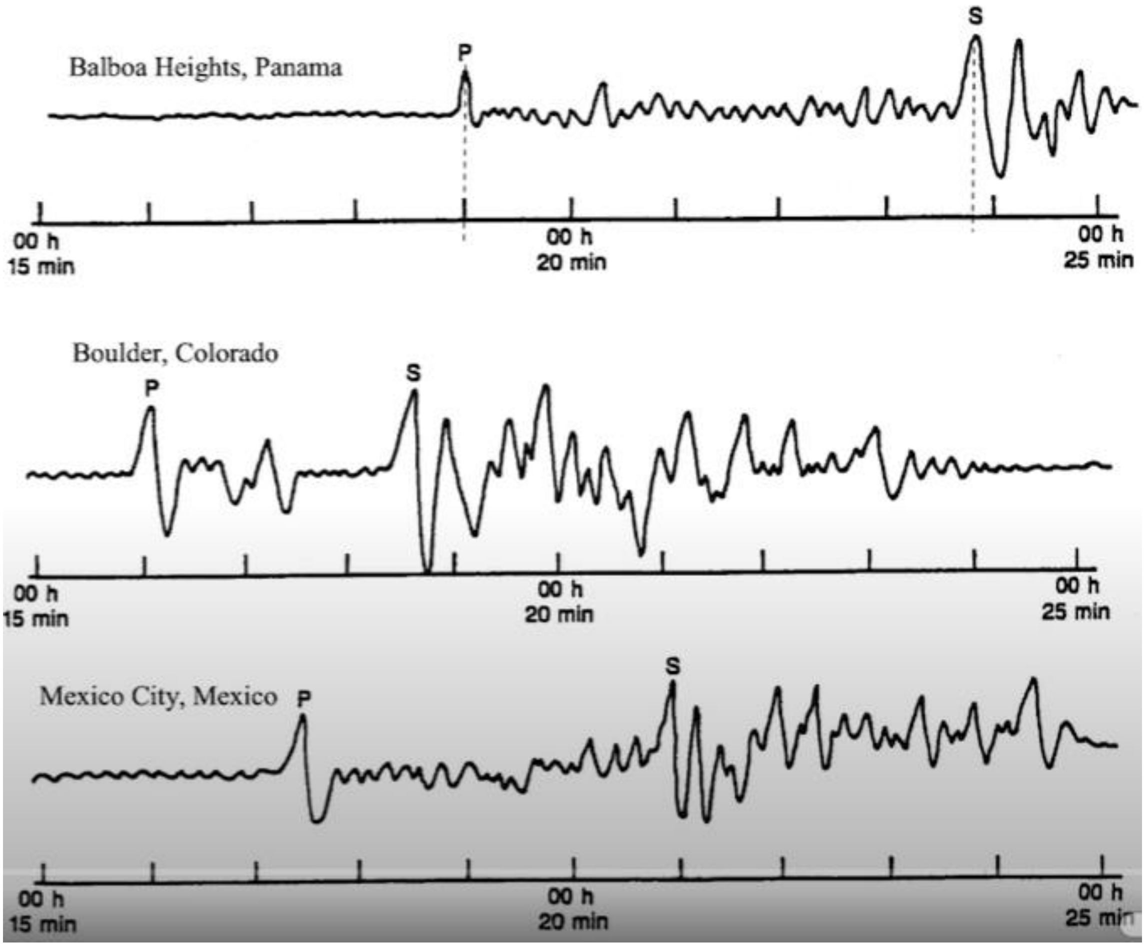


Image: How to Find the Epicenter of an Earthquake

Data table:

City	Difference between P-wave and S-wave	Distance to epicenter
Balboa Heights		
Boulder		
Mexico City		

Earthquake P- and S-wave travel time

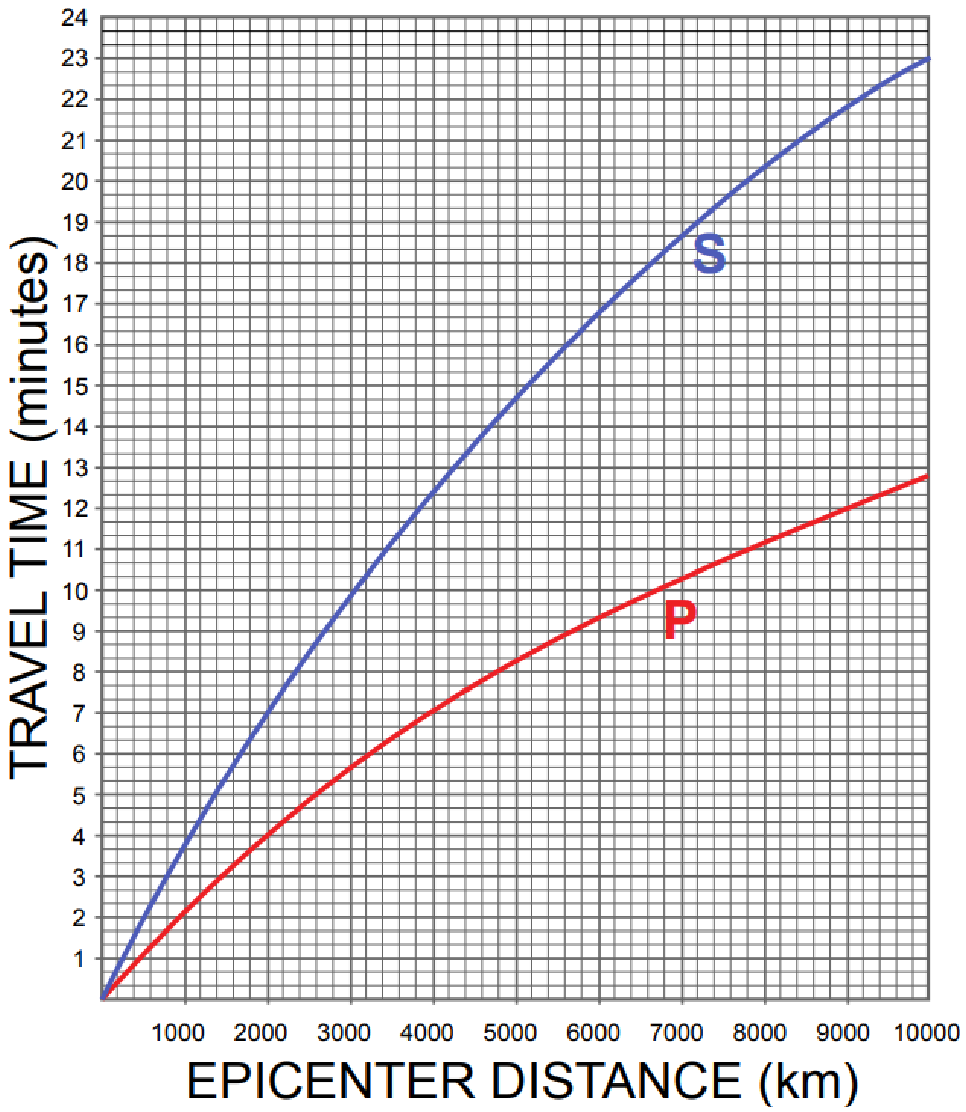
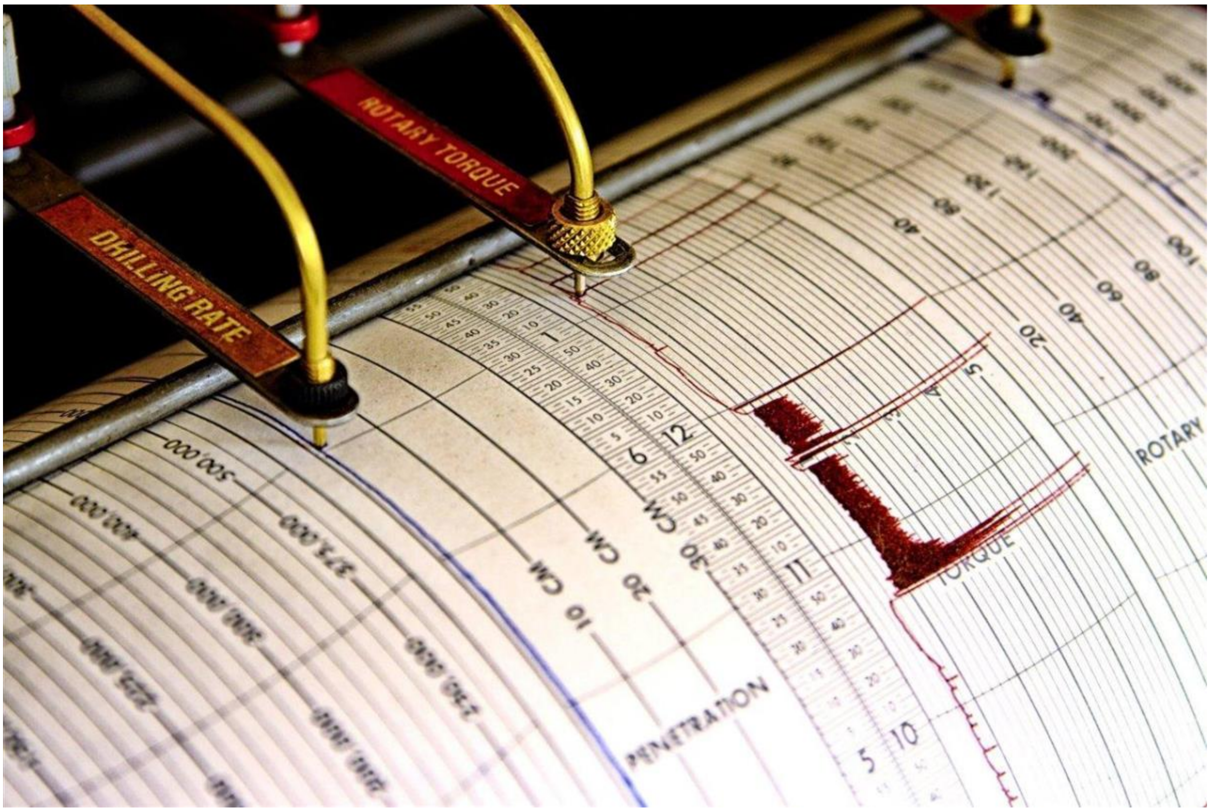


Image: https://d32ogoqmya1dw8.cloudfront.net/files/mathyouneed/p-s_wave_plot.pdf

Image: [How to Find the Epicenter of an Earthquake]

Solution: [How to Find the Epicenter of an Earthquake]

Mathematics annexes: Civically engaged to ensure that an earthquake is not a social issue!



https://www.nationalgeographic.com.es/ciencia/terremoto-como-medir-escala-richter_18965

Justification

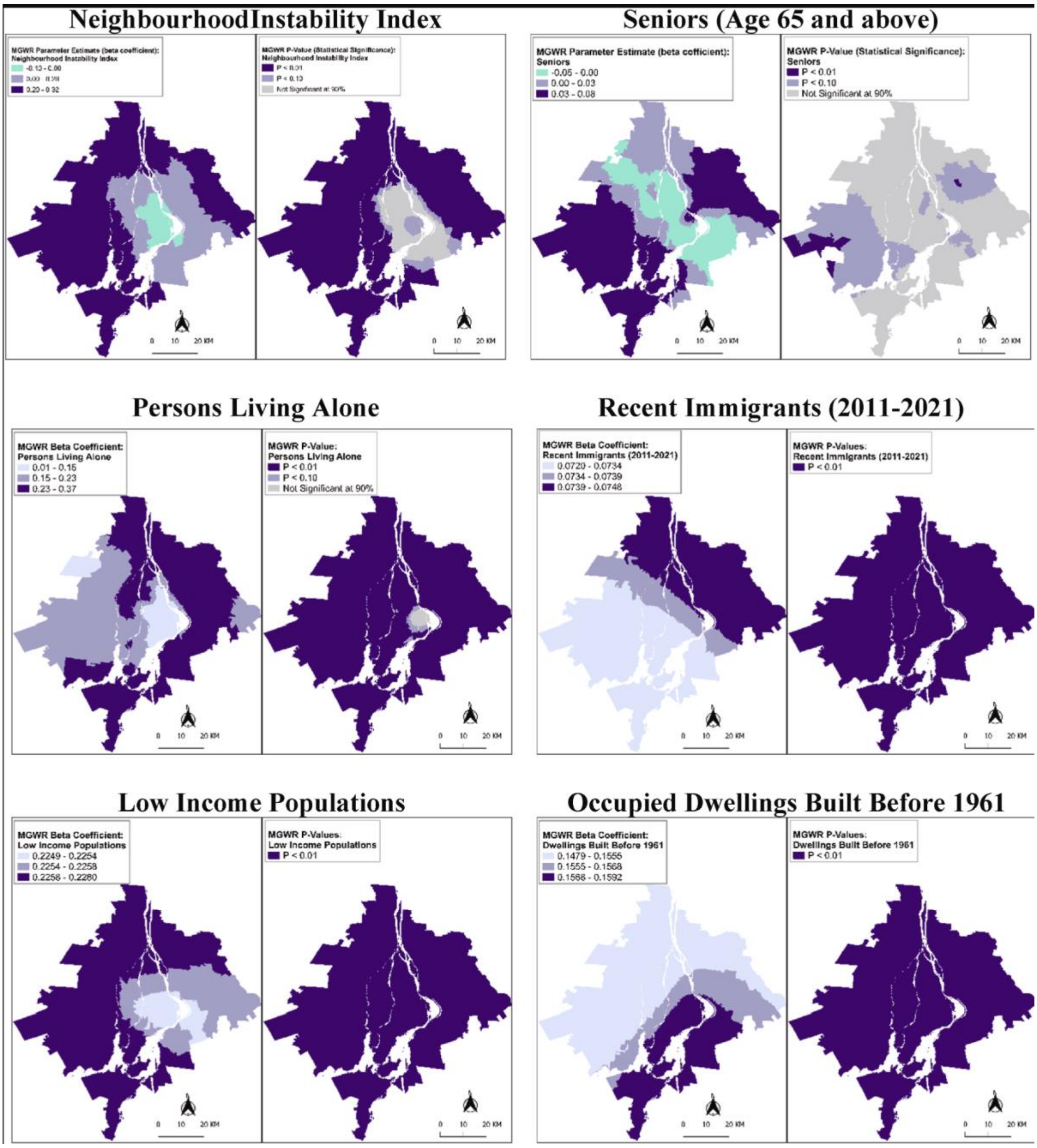
Pre-reading

Imagine a strong earthquake hitting Puerto Real tomorrow. What do you think will happen to your neighbourhood? What do you think would be affected the most?

Reading

Earthquakes are natural events. They happen when the ground suddenly moves because of energy inside the Earth. Many people think earthquakes affect everyone in the same way. However, research shows

that this is not true. Some communities are more at risk than others. Because of this, earthquakes can also be a *social justice issue.*
A recent study in the International Journal of Disaster Risk Reduction looked at earthquake risk in the cities of Montreal and Ottawa-Gatineau. The researchers (Chakraborty et al., 2025) wanted to understand not only where earthquakes could happen, but also who would suffer the most damage.
The study found that earthquake risk is connected to social conditions. People with low income often live in older or weaker buildings. These buildings may not follow modern earthquake safety rules. If an earthquake happens, these homes are more likely to be damaged. In contrast, people with higher income may live in newer buildings that are stronger and safer.
Researchers also discovered that some groups of people are more vulnerable during disasters. For example, elderly people may have difficulty leaving their homes quickly. People who do not speak the main language may not understand emergency warnings (such as those that we have in our phones). Recent immigrants may not know where to find help. Single-parent families may also find it harder to prepare for emergencies.
The following graph illustrates neighbourhood instability, it exhibits a notable positive correlation within seismic risk across the majority of dissemination areas, except for certain southeastern regions of Montreal. Seniors in the eastern and western areas of Montreal demonstrated a significantly positive association with seismic risk. Socioeconomic deprivation indicators, including individuals living alone, recent immigrants, low-income populations, and occupants of dwellings constructed before 1961, showed a significant positive correlation with seismic risk across all areas of Montreal.



Because of these findings, the researchers said that governments must think about fairness and equality in disaster planning. Cities should repair older buildings, improve safety rules, and make sure emergency information is easy for everyone to understand. They should also support communities that have fewer resources.

One way to understand the impact of earthquakes is to look at famous events from the past. One important example for us is the 1755 Lisbon earthquake.

The earthquake of 1 November 1755 is one of the most destructive earthquakes recorded in the annals of the earth sciences, and has

focused on the vision of the event and the philosophical questioning that it provoked. Given the destruction it caused and the impact it had in Lisbon and in the Bay of Cadiz, it left a vast set of documents and iconographic elements that have been used since the beginning of the last century in the study of historical seismology.
The analysis of the historical sources shows that the Lisbon earthquake was a milestone in the field of the perception of nature's "anomalies" and it highlighted man's fragile position in the face of the disruptive effects of an enormous and unexpected cataclysm (Araujo, 2021).
At variance with Lisbon, the Spanish harbour town of Cadiz was considered as miraculously saved, despite fears reported in the citizens descriptions: *"the sea-flood raised fears that the town might be submerged [...] The waters threw down the parapet of the battlement on the West side [...]. There happened to flow about 3 or 4 feet of water in the houses of the small flooded area. The women and three children were drowned there. That is all the harm done to the town by the sea".*
All accounts of the day in Cadiz point to damages in the same area, the western front of the town wall, along the cove and beach called *La Caleta,* between Fort *Santa Catalina* and the jetty to Fort *San Sebastian.*

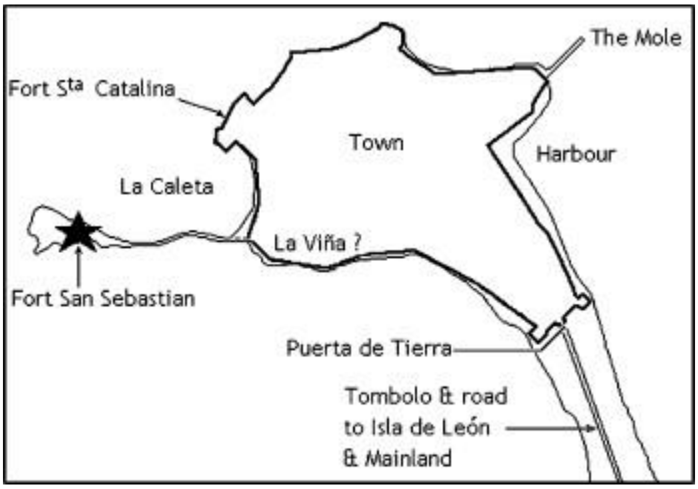


Figure 1. Relative positions of places mentioned in the discussion of damages to the town (Blanc, 2008)
The effects of an earthquake can be generally classified into the following categories:

1. physical impacts,
2. social impacts (the impact on people),
3. economic impacts (the impact on the wealth of an area)
4. environmental impacts (the impact on the landscape).

It has long been a dream of seismologists, geologists, and public safety officials to be able to accurately predict the location, magnitude, and timing of earthquakes on time scales that would be useful for minimizing danger to the public and damage to infrastructure.
Many different avenues of prediction have been explored, such as using observations of warning foreshocks, changes in magnetic fields, seismic tremor, changing groundwater levels, strange animal behaviour, observed periodicity, stress transfer considerations, and others. So far, none of the research into earthquake prediction has provided a reliable method. The problem with earthquake predictions, as with any other type of prediction, is that they have to be accurate most of the time (Earle, 2015).
With the aim of predicting earthquakes the Lincoln Laboratory of the Machachusetts Institute of Technology have established some key features on Artificial Intelligence that they have been developed:

- Algorithmic models are trained on more than 10 years of ionosphere TEC data associated with 10000+ earthquakes,
- Goal is to classify preseismic earthquake signals by magnitude, geographical region, and event window.
- Multiple types of machine learning methods have been tested, demonstrating viability of using TEC data.

Let's look how this machine learning works:
[Can You Help Seismic Researchers and AI Predict Earthquakes?]
Il be the aim of this learning situation, to use Secondary school mathematics to predict the probability of an earthquake occurring in Puerto Real.
We will learn:
MAB.4.A.1.2. Express quantities using real numbers with the required precision.
MAB.4.A.1.3. Different representations of the same quantity.
MAB.4.A.2.1. Perform operations with real numbers in solving contextualized situations.
MAB.4.A.2.2. Inverse properties and relations of operations (addition and subtraction; multiplication and division; squaring and extracting the square root): calculations with real numbers, including digital tools.

MAB.4.B.2. Change. Graphical study of growth and decay of functions in everyday contexts with the support of technological tools: absolute, relative and average rates of change.
MAB.4.D.3. Variable.
Variables: association of symbolic expressions to the context of the problem and different uses.
MAB.4.E.1.1. Strategies for collecting and organizing data from an everyday situation involving a two-dimensional statistical variable. Contingency tables.
MAB.4.E.1.2. Analysis and interpretation of statistical tables and graphs of one and qualitative, discrete quantitative and continuous quantitative variables in real contexts.
MAB.4.E.1.3. Measures of location and dispersion: interpretation and analysis of variability.
MAB.4.E.1.4. Statistical graphs of one and two variables: representation using different technologies (calculator, spreadsheet, applications...), analysis, interpretation and drawing reasoned conclusions.
MAB.4.E.1.5. Interpretation of the relationship between two variables, assessing graphically with technological tools the relevance of carrying out a linear regression. Linear adjustment with technological tools.
MAB.4.E.2.1. Composite experiments: planning, performing and analysing the associated uncertainty.
MAB.4.E.2.2. Probability: calculation using Laplace's rule and counting techniques in simple and compound experiments (using tree diagrams, tables...) and application to informed decision making.

S1 and S2. Recognition of patterns in historic earthquakes

1. Watch the next video https://youtu.be/1jBHvWlRbFE?si=UvYLGt5wzXqzDOqa and summarize how can historical data help predict and prepare for future earthquakes?
2. Think of how many earthquakes have occurred in the Iberian Peninsula and Canary Islands with magnitude equal to or greater than 1.5 in the last ten days.

3. Access the Webpage of the Instituto Geográfico Nacional and research on:
   How many Earthquakes have occurred in the last 10 days of magnitude equal to or greater than 1.5?
   https://www.ign.es/web/en/ign/portal/ultimos-terremotos
4. Access the catalogue of earthquakes from 1370 A.D. to present times and find the data corresponding to the period from 01/01/2015 to today.
   https://www.ign.es/web/ign/portal/sis-catalogo-terremotos
   a. How many earthquakes have occurred since 01/01/2015?
   b. Which variables provide the table?

   If you can not access the table, you can use the table created in :
   IGN_catalogue
5. Access to the CODAP sample of 5000 cases of the Earthquake data and perform a data analysis:
   https://codap.concord.org/app/static/dg/en/cert/#shared=https%3A%2F%2Fcfm-shared.concord.org%2FdCwE7Mq3YwZV5BJnzTTD%2Ffile.json

   i. For the variable deepness, summarize the measures of center, position and dispersion (spread) in a graph and plot them here
   ii. For the variable magnitude, summarize the measures of center, position and dispersion in a graph and plot them here.
   iii. A scatter plot relating the deepness and magnitude and the regression line (least squares line and show fit uncertainty).
   iv. Interpret the results and conclude on the patterns of earthquakes of the last ten years (250 words)
6. The newspapers of the 20 of January of 2015 wrote:
   “A second earthquake in the Gulf of Cadiz in the early hours of last night.
   The seismic movement was 4.2 degrees Ritcher and occurred 60 kilometres off the coast of Cadiz”

   Access to the sample of data of Earthquakes from Golfo of Cadiz that you can find in the next link, and https://codap.concord.org/app/static/dg/en/cert/#shared=https%3A%2F%2Fcfm-shared.concord.org%2FXCYuXmSxMj0h68B0R25O%2Ffile.json

a. Look for temporal patterns for earthquakes with deepness over 60 km and magnitude over 4 mg.
b. Filter those earthquakes fitting both conditions and plot them in a map.
c. Interpret the results and look for patterns.
d. Conclude about the truthiness of the information of the newspaper.

S3 and 4. Understanding conditional probability to predict the occurrence of an Earthquake in Puerto Real

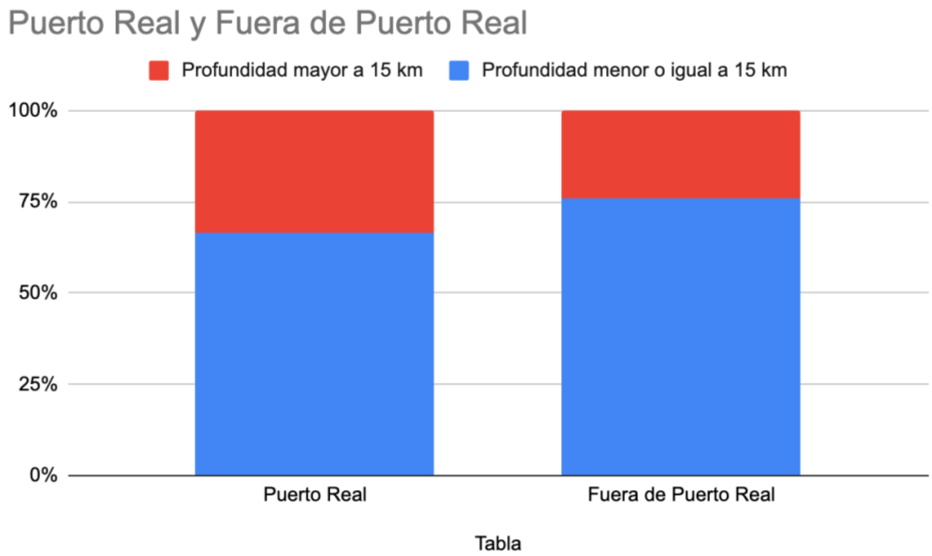
The objective is to determine different probabilities of an earthquake that could affect Cadiz, considering different contingency tables.

A contingency table is one of the most common ways of summarising categorical data. In general, the focus is on whether there is any association between a variable called end and another variable called column and the strength of this association is calculated.

For example, the contingency table associates the number of earthquakes occurring from 1 January 2008 to 2 February 2024 with the depth of the earthquakes.

Table	Puerto Real	Out of de Puerto Real	Total
Deepness smaller or equal than 15 km	2	105392	105394
Deepness bigger than 15 km	1	33486	33487
Total	3	138878	138881

Data can be represented graphically:



If we apply Laplace's rule that says: in the case where all outcomes of a random experiment are equiprobable, Laplace defines the probability of an event A as the ratio of the number of outcomes favourable to the occurrence of event A in the experiment to the number of possible outcomes of the experiment. Thus, we can summarise it with the following formula.

$$P(A) = \frac{Number\ of\ favourable\ cases\ to\ A}{Total\ number\ of\ possible\ cases}$$

Table of probabilities	Outcome A	Outcome no A	Total
Outcome B	P(A and B)	P(no A and B)	P(B)
Outcome no B	P(A and no B)	P(no A and no B)	P(no B)
Total	P(A)	P(no A)	1

In addition, conditional probabilities or so-called ‘a posteriori’ probabilities can be determined:

In an experience composed of two, if A is an event corresponding to the first one and B is an event corresponding to the second one, you have seen how P(B) is calculated considering the different paths by which it can be reached.

Sometimes it is interesting to know the P(A/B), i.e. when we already know that S has occurred in the second experience, we ask ourselves the probability that it has been reached through A.

This is a conditional probability:

$$P(A/B) = \frac{P(A \cap B)}{P(B)}$$

1. Determine using the contingency table in the example above:
    a. Complete the probability table
    b. Calculate the probability that the epicenter of the earthquake was in Puerto Real if we know that it took place at a depth of less than 15km.
    c. Calculate the probability that the epicenter would be Puerto Real if we know that it took place at a depth of more than 15km.
    d. Conclude on the probability of a devastating earthquake in Puerto Real.

We know that earthquakes of magnitude greater than 5 MbLg can cause severe damage in densely populated areas if their epicentre is less than 15 km deep.

2. Determine using the contingency table:

Tabla de contingencia	Magnitud inferior a 6	Magnitud superior o igual a 6	Total
Profundidad menor o igual a 15 km	105390	2	105392
Profundidad mayor a 15 km	33485	2	33487
Total	138875	4	138879

    a. What is the probability of an earthquake with a magnitude greater than or equal to 6 and a depth less than or equal to 15 km?
    b. If we know that the magnitude was greater than or equal to 6, what is the probability that the depth is less than 15km?

3. Access to the IGN catalogue of earthquakes from 1st of January of 2015, that you will find in the next link: https://docs.google.com/spreadsheets/d/1OwZaRX62fqj8AWZHcuG4L-rVQTEURyhA2qjj2pY65b8/edit?usp=sharing

   a. Copy all the columns and launch CODAP: https://codap.concord.org/
   b. Select the table and import a new random sample table from the clipboard.
   c. Select from the three lines the import action and paste the next link, corresponding to the "arbor decision tree algorithm": https://codap.xyz/plugins/arbor/
   d. Perform a decision tree data analysis considering the location, the depth less than 15km and the magnitude more than 6 Mg. Where the earthquake is predicted to take place?
   e. Use the decision tree to construct a contingency table and determine the probability of occurrence of an earthquake of depth less than 15km and the magnitude of more than 6 Mg

4. Run again CODAP with another random sample and perform the decision tree analysis considering the location, the depth less than 15km and the magnitude more than 6. Analyze the difference with the previous sample

5. Conclude on the differences that you can find in both decision tree analysis.

6. Conclude:

   a. What have been the different stages of the study of earthquakes in Spain since you were born?
   b. What is the probability of an earthquake in the Gulf of Cadiz generating a devastating tsunami?
   c. Are the samples chosen sufficiently representative?

7. Understanding what population, sample and sampling is by engaging with Edpuzzle.

S5. Many magnitudes and units of measurement of the magnitude of earthquakes

Before reading

1. Do you know how the magnitude of an earthquake is measured?

During the reading

Read the text: https://www.usgs.gov/faqs/moment-magnitude-richter-scale-what-are-different-magnitude-scales-and-why-are-there-so-many

In the next table we can find some of those magnitudes:

Magnitude Type	Magnitude Range	Distance Range	Equation
Mww (Moment W-phase)(generic notation Mw)	~5.0 and larger	1 - 90 degrees	$M_W = 2/3 * (\log_{10}(M_O) - 16.1)$, where M_O is the seismic moment.
Mwc (centroid)	~5.5 and larger	20 - 180 degrees	$M_W = 2/3 * (\log_{10}(M_O) - 16.1)$, where M_O is the seismic moment.

Mwb (body wave)	~5.5 to ~7.0	30 - 90 degrees	$M_W = 2/3 * (\log_{10}(M_O) - 16.1)$, where M_O is the seismic moment.
Mwr (regional)	~4.0 to ~6.5	0 - 10 degrees	$M_W = 2/3 * (\log_{10}(M_O) - 16.1)$, where M_O is the seismic moment.
Ms20 or Ms (20sec surface wave)	~5.0 to ~8.5	20 - 160 degrees	$M_S = \log_{10} (A/T) + 1.66 \log_{10} (D) + 3.30$.
mb (short-period body wave)	~4.0 to ~6.5	15 - 100 degrees	$m_b = \log_{10}(A/T) + Q(D,h)$, where A is the amplitude of ground motion (in microns); T is the corresponding period (in

			seconds); and Q(D,h) is a correction factor that is a function of distance

After the reading

1. Have you understood the numbers used in each of the equations?

Logarithms can be thought of as “the inverse” of exponents.
For example, we know that the following exponential equation is true:

$$3^2 = 9$$

In this case, the base is 3 and the exponent is 2. We write this equation in *logarithm from as* $log_3 9 = 2$.

Historical note:
Logarithms were developed in the 17th century by the Scottish mathematician, John Napier (1550-1617). They were clever methods of reducing long multiplications into much simpler additions and reducing divisions into subtractions. While he was young, Napier had to help his father; who was a tax collector. John got sick of multiplying and dividing large numbers all day and devised logarithms to make his life easier!

The **logarithm** with base a of a positive real number different of one, b $(b > 0)$ a positive real number, is another real number, c, which accomplishes that the base oa to the exponent c is equal to b:

$$log_a b = c \iff a^c = b \text{ donde } b > 0, a \in (0,1) \cup (1, \infty)$$

Read carefully the definition to establish:

a. Which is the relationship between the base of the power and the base of the logarithm?
b. Which is the relationship between the exponent of the power and the value of the logarithm?
c. Why should the base of the algorithm be different from 1?

S6. Graphical representation of the moment magnitude

The amount of energy released by an earthquake from the Seismic Moment is defined as follows:

MO = : DA

where MO is the seismic moment, measured in dynes-cm: is the stiffness of the rock in dynes/cm2 , D is the average fault displacement in cm and A is the area of the ruptured segment expressed in cm2.

The new magnitude scale, called moment magnitude, was developed by Hiroo Kanamori of the California Technological Institute. The following expression is used for its determination:

MW =2/3 log MO - 10.7

The magnitudes of large earthquakes were calculated using this new scale and for some of them it changed notably, such as the Chile earthquake of 1960 which had a MS magnitude of 8.3 and when calculating the ‘moment magnitude’ it was 9.5.

Después de la lectura

If we consider MO the independent variable and assign it 'x' and MW the dependent variable and assign it 'y', we can plot the function that determines the moment magnitude (MW) from the amount of seismic moment (MO).

For that,

1. Access to GeoGebra classic (https://www.geogebra.org/classic) and write in the bar of entries:

   $$y=\frac{2}{3}\log x-10.7$$

   a. Observe the graph and determine:The domain
      1. The range
      2. The points of intersection with the X and Y axes
      3. The Continuity
      4. The intervals of growth and decay
      5. The maximum and minimum
      6. The concavity and convexity
      7. Periodicity

Recuerda que:

The **rate of change** of a function is the growth or the decay that this function experiences from one value to another of the abscise axes X. $\mathbf{RC[x_1,x_2]=f(x_2)-f(x_1)}$

The average rate of change of a function y=f(x) from x=a to x=b is:

$$ARC=\frac{f(b)-f(a)}{b-a}$$

2. Find the rate of change and the average rate of change of the seismic moment :

   $a = 50{,}80x10^{20}$ din/cm² (correspondiente al sismo ocurrido el 25/09/2016 en S Cúllar. GR)

$b = 32{,}70x10^{24}$ din/cm^2 (correspondiente al sismo ocurrido el 25/01/2016 en Alborán Sur).

3. Interpret the rate of change and the average rate of change to understand the growth of the function of the moment.
4. Draw the function función: f(x)=log_2(x)
   a. Construct the table of values:

x	1/4	1/2	1	2	4
y=f(x)					

   a. Analyze the domain, range, intersection with the axes, continuity, growth and decay, maximums and minimums, concavity and convexity.
   b. Compute the rate and the average rate of change for $x_1 = 1$ and $x_2 = 4$
5. Draw the graph of each of the following logarithmic functions with the help of GeoGebra (https://www.geogebra.org/classic), analyze its properties and find the average rate change for x=4 to x=6:
   a. f(x)=log x
   b. f(x)=-log(x-3)
   c. f(x)=$log_2(x+2)$

S7. Final product. Write a journalistic article

1. Read on which are the hallmarks of journalistic writing: https://writingcenter.uagc.edu/journalistic-writing
2. Write a journalistic article based on the data and graphs that you have produced during the learning situation with the title:

   Are you afraid of an earthquake in Puerto Real, yes or no?
3. Analyze if your journalistic article accomplishes the principles of simplicity, brevity, precision, objectivity, factual accuracy, fairness and balance and inverted Pyramid.
4. Improve your article if necessary.

Bibliography

Araújo, A. C. (2021). The 1755 Lisbon Earthquake: The Catastrophe and the Reconstruction, "Storicamente", 17 (2021), no. 5. https://doi.org10.52056/9788833138732/05

Almagro. M. (09/03/2015). ¿Qué probabilidad hay de que haya un terremoto en Cádiz? *Voz de Cádiz.* https://www.lavozdigital.es/cadiz-provincia/201503/07/terremotos-posible-cadiz-20150304160610-pr.html

Blanc, P. L. (2009). The tsunami in Cadiz on 1 November 1755: A critical analysis of reports by Antonio Ulloa and by Louis Godin. *Comptes Rendus Geoscience, 340*(4), 251-261.

Earle, S. (2015). Physical Geology. *BCcampus.* https://opentextbc.ca/geology/chapter/11-5-forecasting-earthquakes-and-minimizing-damage-and-casualties/

Chakraborty, L., Spinney, J. A., Malomo, D., Thistlethwaite, J., Motlaghzadeh, K., Jahangir, M. S., Henstra, D., Andrews, S., & Pulatsu, B. (2025). Assessing the environmental justice implications of seismic risk in Ottawa–Gatineau and Montreal metropolitan areas. *International Journal of Disaster Risk Reduction, 123*, 105516.

Glatzmaiers, G., Roberts, P. A three-dimensional self-consistent computer simulation of a geomagnetic field reversal. Nature 377, 203–209 (1995). https://doi.org/10.1038/377203a0

IGN (s.d.). Historia del Instituto Geográfico Nacional. Recuperado de: https://www.ign.es/web/ign/portal/qsm-nuestra-historia

IGN (s.d.). Catálogo de Terremotos. Recuperado de: https://www.ign.es/web/ign/portal/sis-catalogo-terremotos

IGN (s.d.). Descripción del tipo de Magnitud. Recuperado de: https://www.ign.es/web/resources/docs/IGNCnig/SIS-Tipo-Magnitud.pdf

Población, A. J. (25/11/2019). Para qué sirven los logaritmos: dos retos sin usar la calculadora. *ABC Ciencia*. Recuperado de: https://www.abc.es/ciencia/abci-para-sirven-logaritmos-retos-sin-usar-calculadora-201911250122_noticia.html

UAGG (2025). Journalistic Writing. *The University of Arizona. Global Campus. Writing Center.* https://writingcenter.uagc.edu/journalistic-writing

USGS (s.d.). Moment magnitude, Richter scale -what are the different magnitude scales, and why are there so many?.

https://www.usgs.gov/faqs/moment-magnitude-richter-scale-what-are-different-magnitude-scales-and-why-are-there-so-many