INTRODUCTION

General Instructions:
The completion of this Lab does NOT require a formal Lab report or write up. Instead you will present your data by completing a Lab Template LAB2: PERMEABILITY shown below. This template is available as a separate document. Only the completed **LAB2: PERMEABILITY RESULTS** needs to be turned in for credit!!!

Reading Assignments:
In preparation for this Lab, READ the following in your FREE Open Access Textbook(s):
•   Kresic, 2024, Hydrogeology 101: Lecture 3.1 through 3.2
•   Freeze & Cherry, 1979, Groundwater: Section 2.1 through 2.5
(Optional) and if you have it, READ the following in your *optional* Textbook:
•   Hölting & Coldewey, 2019, Hydrogeology: Section 4

The following short explanations may also be helpful in your understanding of this Lab:

Permeability is a measure of the ability of rock or soil to transmit fluid. In short, porosity is not enough. All the pores must also be connected to transmit fluid. The quality of those connections AND the pore space is **permeability**. For your information, when discussing permeability, the following mathematical relationship might be helpful:

$$k \approx C*d^2$$ Where k = intrinsic permeability. C and d are interesting, for they describe the soil attributes of permeability. C is a dimensionless constant depending on porosity, particle size, shape of grains, etc. d = mean grain diameter.

Permeability is usually measured in Darcys (Where have I heard this name before?). One Darcy exists when in a certain amount of time a certain amount of fluid (with a certain viscosity) under a certain pressure is squeezed through a certain areal cross section. The unit of measure of a Darcy is area, cm^2.
Hint: The USGS uses **intrinsic permeability** in micrometers squared (μm^2). Intrinsic permeability is a little different from a Darcy: 1 Darcy = 9.87 * 10 $^{-9}$ μm^2 Intrinsic Permeability.

Permeability which is analogous to **hydraulic conductivity** in hydrogeology is based on the concept of Darcy's law (the $e=mc^2$ of hydrology), which states:

$$Q = k_f \times A \times \frac{h}{l}$$

Where
Q   is the amount of water passing through a medium per unit time (m^3/s)
k_f is the medium-specific Coefficient (m/s). This is the one we need for permeability.
A   is the surface area of the medium perpendicular to the flow (m^2)
h/l   is the hydraulic gradient... or the change in elevation per unit length of flow.

Darcy's law equation can be solve for k_f, the unit indicating permeability.

GENERAL INSTRUCTIONS ON COMPLETING THE LAB and GRADING:

For ALL assignments use a citation's database:

ZOTERO citations database	ZOTERO is a citations database that incorporates itself into Word and your Browser.	Free open source software available at https://www.zotero.org/

Note: You may use a different citations database, if desired. But you MUST use a citations database!

NOTE: After downloading and installing ZOTERO, take an hour or two to become familiar with the operation of the software. One of your first tasks will be to set the citation style to the United States Geologics Survey (USGS) format in ZOTERO. The USGS citation system will be required for this course and your final product.

>   **Loading the USGS citation format into ZOTERO:** Once Zotero Standalone is installed, click on "Preferences" under the Edit tab. Once there click on "Cite" and go to the "Styles" tab. Click on the "Get additional styles..." below the Styles Manger Box. When the Zotero Styles Repository Window opens, click on the "geology" button within the "Fields" section. A list of geology journals should now appear. Scroll down to the U.S.Geological Survey and click on it. The U.S.G.S style will now be part of your Zotero system and you can set your citations to be formatted accordingly in Zotero.

General Writing Instruction Summary:
- Use professional language, which means AVOID first person expressions such as "I", "we", "our". Use normal prose, active voice and third party language. Do NOT use informal wording, contractions, jargon, slang terms, or superlatives. Exclude similes/metaphors (and humor!)
- Use present tense to report well accepted facts, e.g. 'Pyrite is a sulfide mineral'. Use past tense to describe specific results, e.g. 'When acid was applied, the specimen effervesced'
- Be quantitative wherever relevant (stats, numbers etc.).

Subscript & Superscript	Use appropriate subscript and superscript, especially when it comes to chemical formulas and mathematical units..

Acceptable examples: 2.9 g/cm^3, H_2O, PO_4^{3-}, $a_g=9.8 m/s^2$
Unacceptable examples: 2.9 g/cm3, H2O, PO4 3-, ag=9.8m/s^2

- Use precise concrete language, no ambiguity e.g, 'correlated' ≠ 'related'. Use simple language – no unnecessary "frills" (distractions). Pay attention to sentence structure and grammar

COMPILING TABLES, FIGURES and EQUATIONS
GRAPHICS are the heart of any report. Nothing is more true than in science that a picture is worth a thousand words. Always compile graphics first and then write your text focusing on your graphic. In order to create good graphics and photographs, follow the instructions below.

Cameras and Photos:
Cell phones with a 7.2MP camera are usually ok. When taking pictures, lighting and background is key. This means dark objects should be photographed with light or white backgrounds (sheet of paper) and visa versa for light objects. Having adequate lighting will also help to get sharp, crisp, in focus pictures. Blurry and out of focus pictures are not acceptable.

Graphics:
You should be able to modify, enhance, annotate or overlay graphics. Minimum resolution is 300dpi. Make sure graphics are crisp, clear and any label is easily readable. All graphics should have a caption stating the author and/or citation. Preferably use lossless graphic formats, such as .tif or .bmp. Unfortunately .jpg is NOT lossless and will degrade a little every time you open and save it again in order to manipulate picture contents.

> **Graphics Editor Software**: You will need a graphics editor and learn how to use it. Windows comes with its default Windows Paint editor. It is found in the Windows Accessories Folder. For a more advanced option with many more professional features you may try GIMP: https://www.gimp.org/ This is a FREE, open source image editor working across all computing platforms (Windows, Apple, Linux, etc.). The software comes with ample documentation and examples on how to manipulate any picture or graphic.

> **Screen Capture Software:** A screen capture or snipping software is advantageous in order to only grab the part of a graphic from the screen that is important or necessary. Windows 10 comes with a default snipping tools, such as "Snip & Sketch" found in its own folder or "Snipping Tool" found in the Windows Accessaries Folder. Note: When snapping a picture, make sure it is large enough on the screen to capture enough pixels to have adequate resolution for the final product.

NOTE: Compiling acceptable and good looking graphics and photographs is very involved and can not be rushed. These are often the heart of any report and should be compiled BEFORE writing. Last minute thrown together graphics will without doubt lower your grade.

COMPOSITION, LAYOUT, WRITING & GRAMMAR SUMMARY
Language
The following list is an example of common faults in language usage and attribution.

Errors / Mistakes / Faults	Examples with margin *Fault Counts & Codes*	
Spelling: incl. capitalization errors & spacing	|| |	The mineral florite has a mohs hardness of four. Nicolas Steno was trained in the classical texts on science.
Grammar: incl. punctuation, superfluous words, transpositions	| ||	Isometric crystals are also isotropic Here light propagates at the same speed. Rocks are composed of many many (minerals mixed.)
Style: incl. paragraph, repetitive expressions / words erroneous expression / words, sub- or superscription, unprofessional style, word insertion	*|Para.* *||rep* | *|sup* || |	... in the geologic sciences.¶Near the end of the 19th a new theory ... ... is a light colored mineral. These light colored minerals are often light... Stalactites hang from the sealing? of a limestone cave. The density of quartz is 2.65 g/cm3. I was investigating the outcrop with my group. Sodium sulfate forms a chalky, incoherent precipitate. *amorphous?* ∧
Sentence: incl. grammar, run-on, strings of nouns	| | ||	The density of gold is greater then? the density of silver. Pyrite has a symmetrical crystal structure, it is cubic. Skarn mineral zonation? is apparent in the sample.

Content
Errors in content are spelled out. Severe infractions may count for multiple errors.

Errors / Mistakes / Faults	Examples with margin *Fault Counter & Codes*	
Unclear / erroneous statements	*|unclear, units?*	Mohs hardness of the mineral in question is 16.5.
False / nonsense	*||Nonsense*	Glaciation cause severe metamorphism of the region

TABLES, FIGURES & EQUATIONS SUMMARY

Tables	Each table must be sufficiently complete that it could stand on its own, separate from text.
	Only HORIZONTAL lines are allowed in tables. Do NOT use any VERTICAL lines.
	DO consecutively number and caption tables and refer to them accordingly within your text. Captions go ABOVE the table. DO provide a short description of your table within the caption. DO place your tables appropriately, closest to their mention in the text. DO make sure tables are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum. DO appropriately label columns. Do NOT forget units for numeric values.
	AVOID splitting tables across pages.

Figures	Each figure must be sufficiently complete that it could stand on its own, separate from text.
	DO number and caption figures consecutively and refer to them accordingly within your text. Captions go BELOW the figure.
	DO provide a short description of your figure within the caption.
	DO place your figures appropriately, closest to their mention in the text.
	DO use appropriate citations for figures that are NOT your own. If you use a figure that has been modified by you, the phrase "modified after...." is most appropriate. Photos should show the name of the photographer.
	DO make sure figures are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum. Use a minimum resolution of 300dpi. This is a common publication standard.
	AVOID cluttering of figures with too much detail. Simplify if necessary.
	AVOID moire patterns in photos, a nuisance in copied or scanned pictures. Most scanners come with a moire pattern removal tool.
	GRAPHS
	Understand graphs: Bar graphs and/or line graphs are used when plotting nominal vs. ratio or interval data. Scatter plot graphs are used when plotting numeric vs. numeric data.
	DO make sure that the graph axis are appropriately labeled and scaled. Axis should have titles as well as scalar units.
	DO use electronic means to generated graphs. Hand drawn graphs are no longer acceptable.
Equations & Computations	☐ Equations should contain explanation of symbols used.
	☐ A reader should be able to follow where your values or numbers come from. Indicate accordingly.
	☐ WRITE DOWN UNITS!!!!
	☐ Show equations used before indicating any computation

Acceptable Example: $F = m \times a = 0.034 kg \times 9.8 \, m/s^2 = 0.33 \, kgm/s^2$

where *m* is mass of the object in kg as determined with a triple beam balance and *a* is the gravitational acceleration. *F* indicates force expressed in kgm/s^2 or *N* (Newtons).

Unacceptable example: The answer is 0.33. This is obtained by multiplying gravity by 0.034.

1 MEASURING HYDRAULIC CONDUCTIVITY IN AN UNCONSOLIDATED SOIL SAMPLE

I. HYDRAULIC CONDUCTIVITY TESTING

There are two standard LAB experiments for establishing k_f. Basically a certain volume of water is "forced" through a soil or rock sample of known volume (diameter, height) and the length of time needed for the particular flow is clocked.

The standard experiment uses a constant gradient, or a constant head (height) of the water level. This experiment is a little bit more elaborate to set up. It is commonly used for sediments of higher permeabilities such as gravels and sands.

During this lab exercise you will use a simplified version commonly used for samples of lower permeabilities such as fine sands, clays and mudstones. The experiment uses a change in the hydraulic gradient (falling head) and the time it takes for this change to occur. From this, hydraulic conductivity and hence permeability can be derived. The experimental set-up is a Tube Type Falling Head Permeameter as pictured, the same set-up you used in LAB 1.

Note: You will save clean-up and time by measuring effective porosity first (LAB 1) and then continued with the hydraulic conductivity test using the same sample.

Procedure for establishing hydraulic conductivity using the permeameter tube:

1. Calculate the cross-sectional area of the permeameter tube (*a*) in m².
2. Either use sample already in prepared tube from porosity experiment (Lab 1) and continue with step 5., or...
3. Place filter paper cut out on the bottom of permeameter tube.
4. Fill the lower part of the tube with 100.00g of soil. Make sure soil is the same as used in porosity determinations.
5. Water saturate your soil sample by carefully filling the tube with water and letting enough water run through the soil until saturated. You should see the wetting front move through the sample. Water should drip out of the open valve for a while.
6. Measure sample height (*l*) in meters and record. Also, calculate the cross-sectional area of the sample (*A*) in m².
7. Close the valve on the bottom of the permeameter tube.
8. Fill water to an arbitrary height of h_1 in the permeameter tube. Mark this height, measure in meters from bottom of sample and record.
9. Start timer as soon as you open the valve (t_0). Let experiment run until water level has dropped a few centimeters in the permeameter tube to level h_2. For very fine grained samples this can take hours. Stop timer as soon as you close the valve and record time t_1 in seconds. Measure and record h_2 from the bottom of the sample.
10. In order to calculate hydraulic conductivity (k_f) from a falling head permeameter data, the following equation was devised. You are calculating hydraulic conductivity in meters per second using measurements with changing gradients:
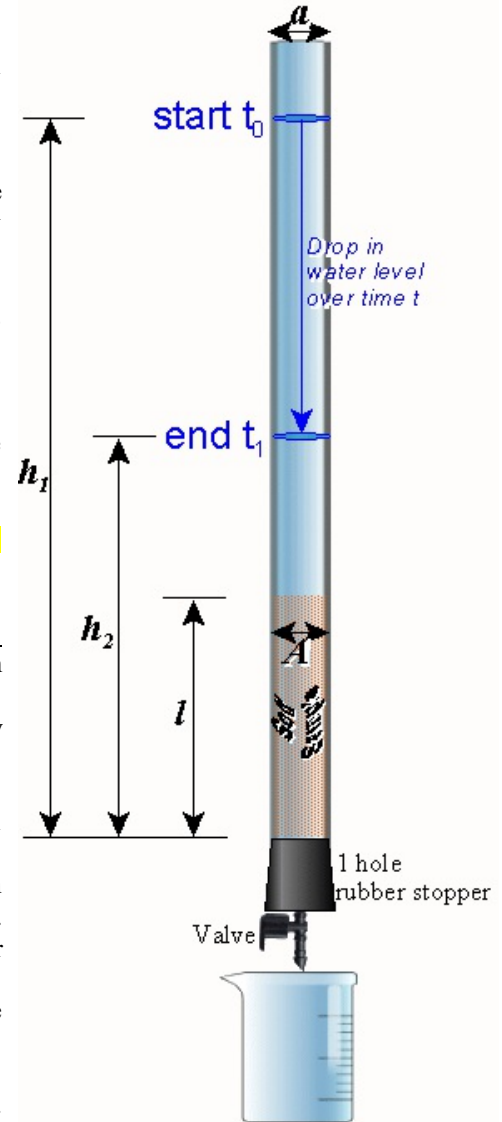
$$k_f = \frac{a \times l}{t \times A} \times \ln\frac{h_1}{h_2}$$

Where
t is the time it took to change from h_1 to h_2 in seconds
l is the length (height) of the sample in meters
h_1 is the height of water in m at experiment start measured from bottom of sample
h_2 is the height of water in m at experiment end measured from bottom of sample
A and a are both the cross-sectional areas [$(d/2)^2 \times \pi$]

Small a designates the cross-sectional area of the water above the sample in a smaller vessel or long, narrow burette used in professional laboratory equipment, resulting in different cross-sectional areas for sample and water column. Since we have the same diameter for the sample and the water above, our original falling head permeameter equation can be simplified. Derive a simplified version of the k_f equation above if A is equal to a.

Use YOUR derived simplified equation for your hydraulic conductivity calculations!

If the lab was successful, you should roughly obtain the following (very small numbers...)

pea gravel	10^{-1} to 10^{-2} m/s	*18.3 to 1.8 ft/min*
coarse sand	approx. 10^{-3} m/s	*2.19 in/min*
medium sand	10^{-3} to 10^{-4} m/s	*2.19 to 0.22 in/min*
fine sand	10^{-4} to 10^{-5} m/s	*13.14 to 1.31 in/hr*
loamy sand	10^{-5} to 10^{-7} m/s	*1.31 to 0.013 in/hr*
sandy clay	10^{-6} to 10^{-9} m/s	*3.14 to 0.003 in/day*
clay	$< 10^{-9}$ m/s	*< 1 in/yr*

The value of hydraulic conductivity or k_f in meters/second relates to **permeability** of rock and soil.

SHARE YOUR DATA WITH OTHER STUDENTS

Make sure you email or use CANVAS to share the following results with ALL other students in the class:

1.   Short description of soil / sample used
2.   Bulk porosity from LAB 1
3.   Hydraulic conductivity k_f from LAB2
4.   Effective porosity n_e from LAB1

2 HYDRAULIC CONDUCTIVITY (kf) IN RELATION TO POROSITY

You will need:
- ☐   Graph Paper (Excel)
- ☐   Colored pencils (Excel)
- ☐   Data from other students

Please use EXCEL for the following:
1.   Compile the porosity (LAB 1), k_f (LAB2) and n_e (LAB1) data from the other students into an Excel spreadsheet.
2.   Create a scatter plot of porosity (n) versus hydraulic conductivity (k_f).
3.   Create another scatter plot of effective porosity (n_e) versus hydraulic conductivity (k_f).
4.   Interpret the graph!
   a.   Are the values dependent on each other? Hint: If you see a pattern, such your data points falling on a straight line or curved path: YES. If your data points are randomly all over: NO.
   b.   Can you predict the one value, if you know the other? If the data is related, try a straight line model. Remember y = mx + b.

Only turn in the [LAB2: PERMEABILITY RESULTS](#) page for grading after completion.