Exploring for "blind" fault-hosted geothermal systems using low temperature thermochronology and thermo-kinematic modeling: a pilot study on the Kigluaik normal fault near Nome, Alaska

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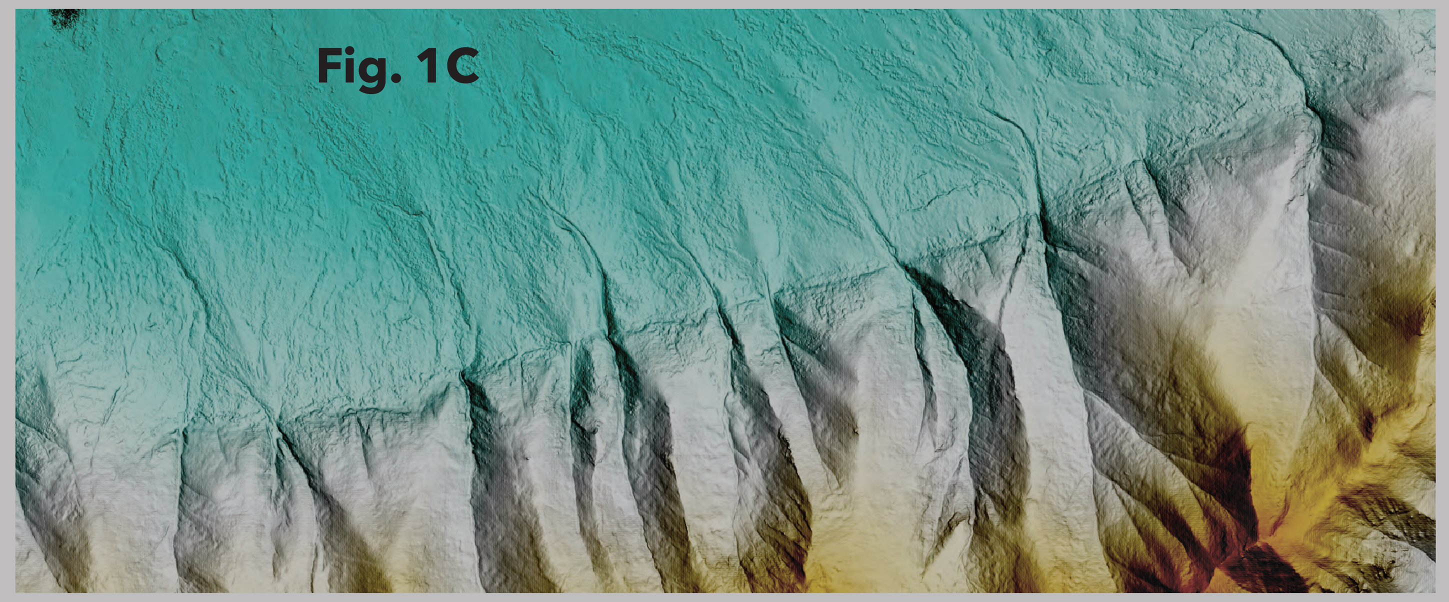
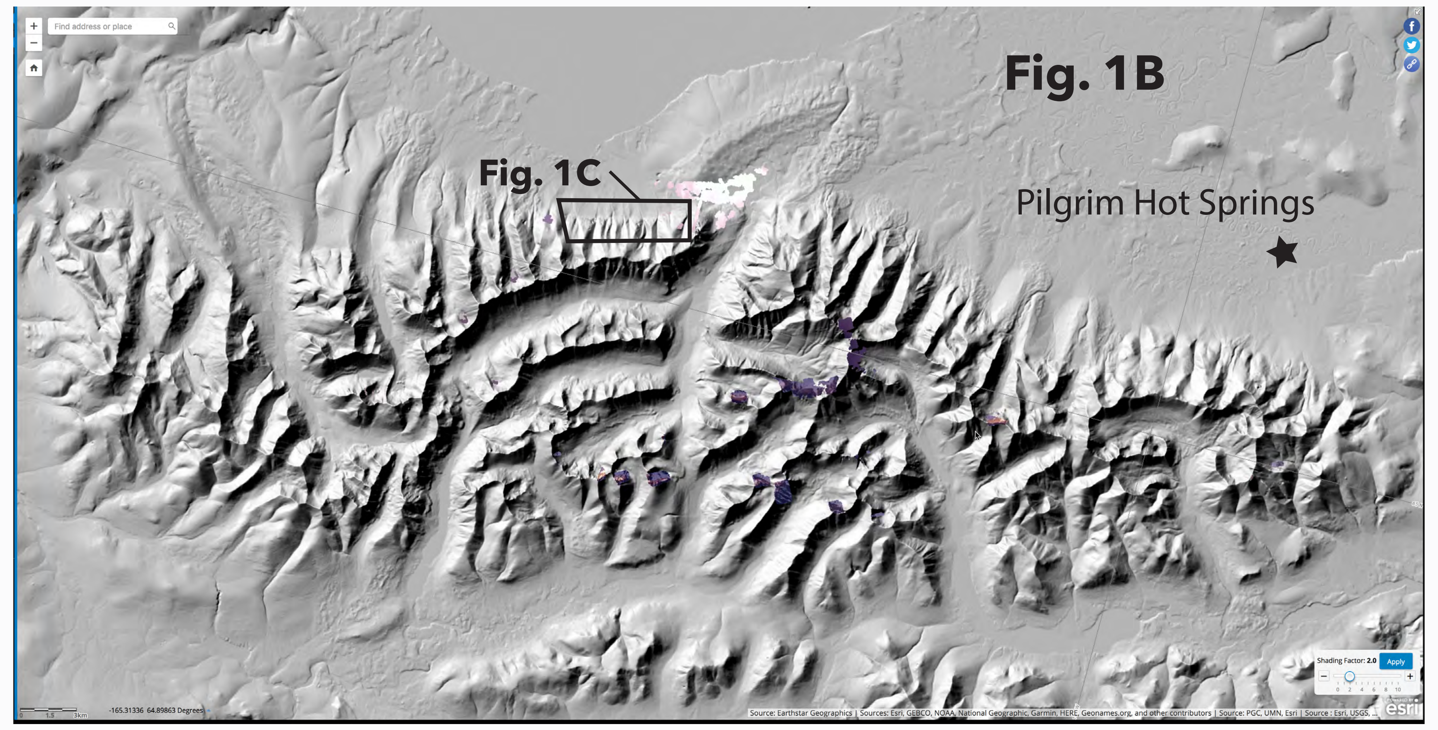
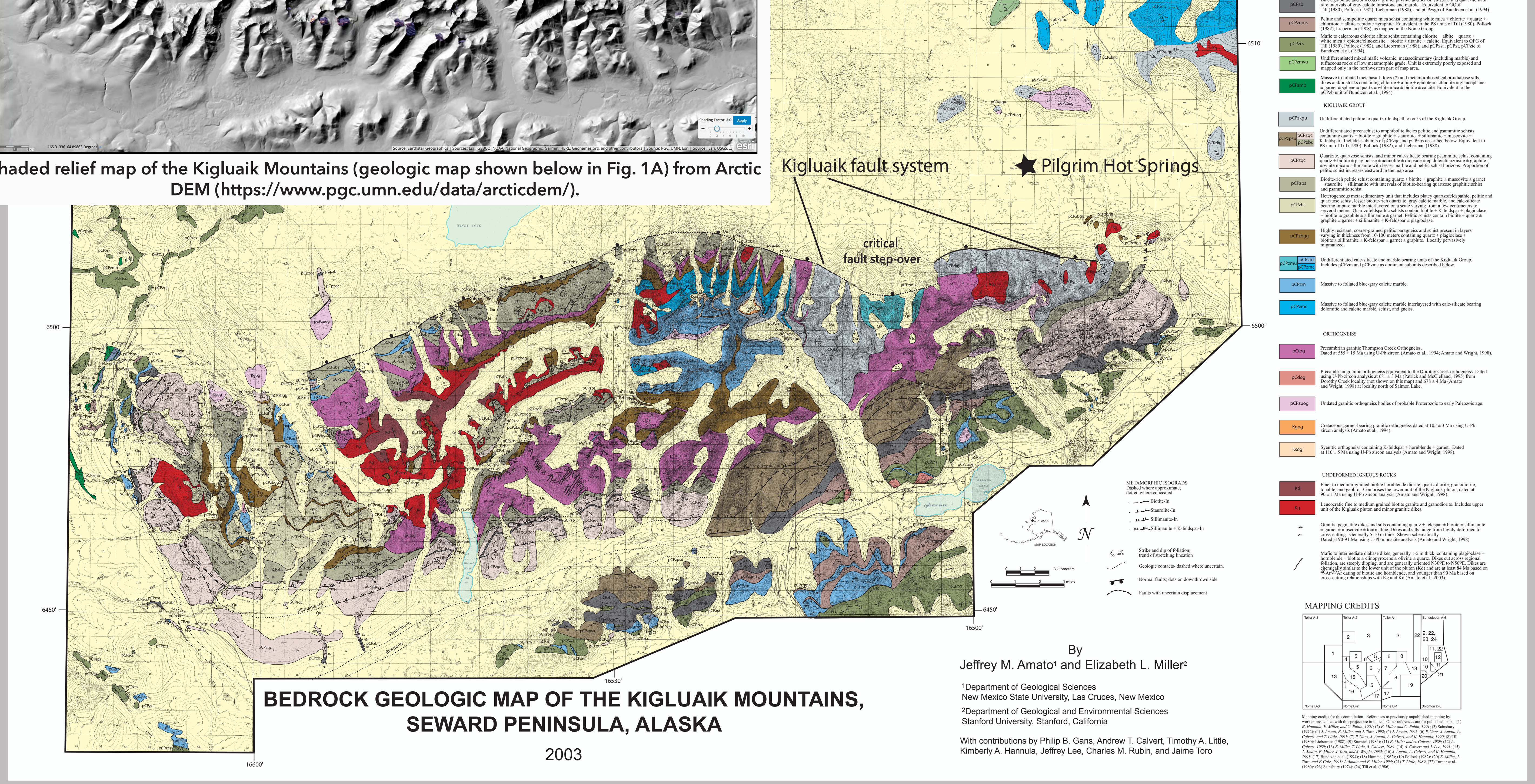


Shaded DEM image of a portion of the Kigluaik fault showing quaternary ruptures (flown by ZGM) For location see box in Fig. 1B below



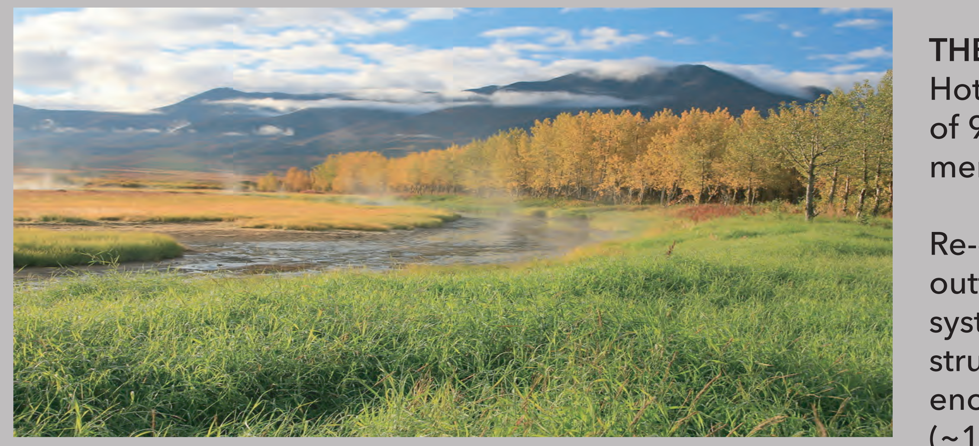
Shaded relief map of the Kigluaik Mountains (geologic map shown below in Fig. 1A) from Arctic DEM (https://www.pgc.umn.edu/data/arcticdem/).



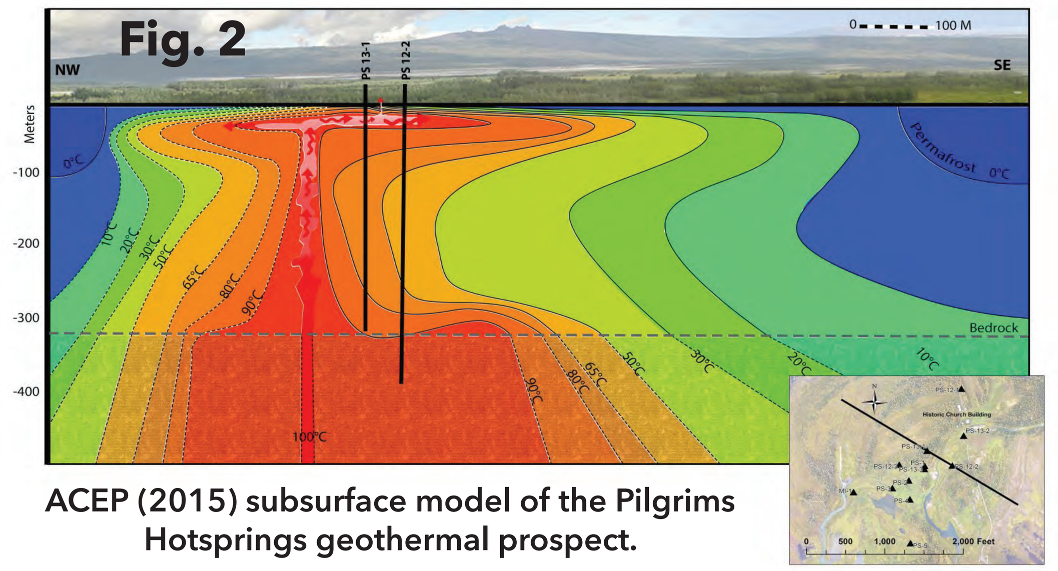
PROJECT DESCRIPTION: Geothermal energy serves a critical role in the transition to a carbon-free energy future. As an effectively emission free source of power it can serve as the dispatchable complement to intermittent sources like wind and solar. A power source whose efficiencies are increased in colder climates, it offers an important means to decarbonize Arctic societies where high latitude and extreme climates make solar, wind, hydro, and battery sources of energy significantly less cost-effective. To date, high up-front capital costs and the risks of drilling dry holes during exploration has hindered its development.

A major uncertainty in exploration for natural geothermal systems is whether an active fault mapped at the surface is permeable at depth and is acting as an upwards pathway for hydrothermal fluids. Tools that can assess the fluid flow history and the present behavior of long-lived active or recently re-activated faults prior to drilling are therefore critical. A promising means for doing so is the high-resolution characterization of thermal histories from rocks within and increasingly distant from the surface trace of major faults using what are known as low-temperature thermochronological methods. Low temperature thermochronometers such as the U-Th/He and fission track systems in the mineral apatite are sensitive to even short-lived thermal disturbances and thus offer the potential to quantify hydrothermal circulation histories. Collecting this kind of data rapidly and affordably is now possible thanks to dramatically declining costs in mass spectrometry and improved computational modeling, making it a novel,cost-effective and underutilized tool for geothermal exploration.

The proposed study seeks to demonstrate the utility of using low-temperature thermochronology methods in assessing the geothermal potential of an active regional fault system in western Alaska. Combined with 3D geologic modeling, the results of this study are anticipated to 1) generally refine our understanding of "blind" geothermal systems (i.e. naturally occurring commercial-grade geothermal systems that have no hot springs or obvious hydrothermal activity at the surface), and 2) specifically test if previously unexplored extensional fault-controlled geothermal systems exist within the state of Alaska.



Pilgrim Hotsprings looking S to Kigluaik Mts. photo credit R. Benoit, flickr



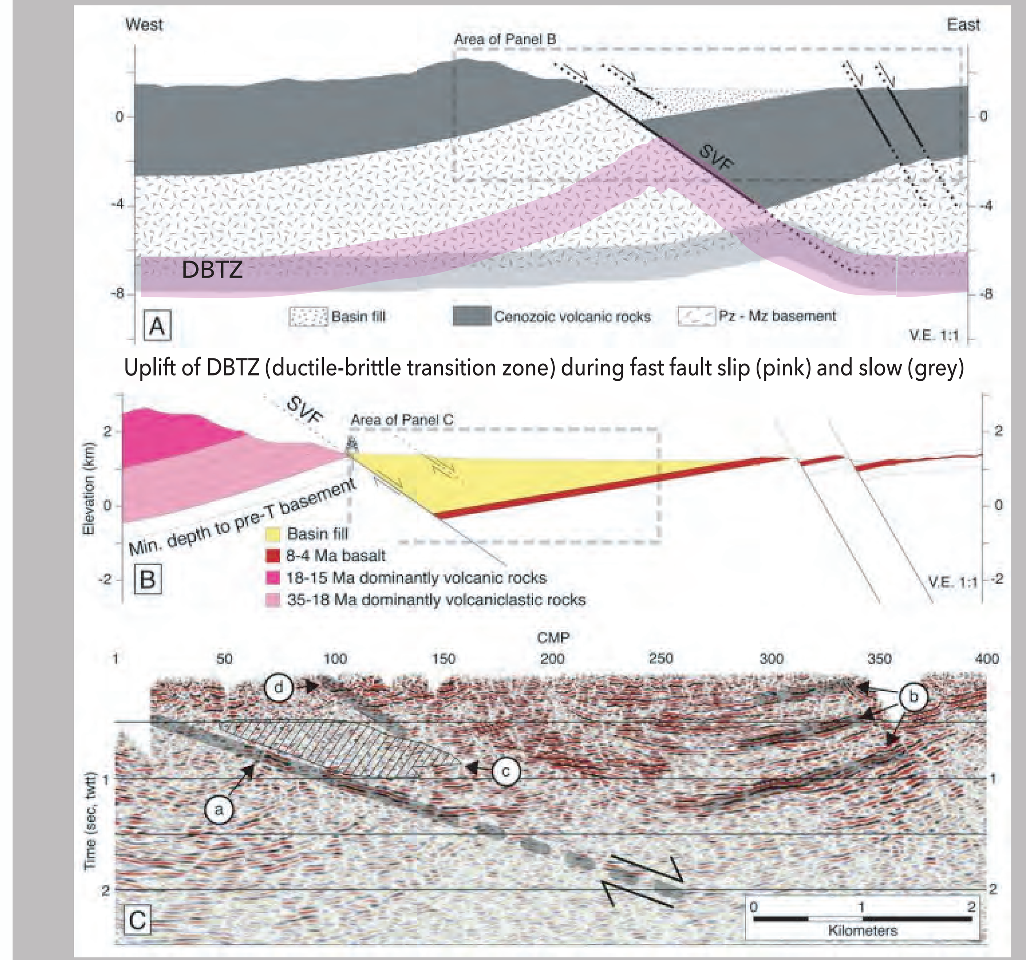
ACEP (2015) subsurface model of the Pilgrims Hotsprings geothermal prospect.

THE PROBLEM: Previous studies in this region of Alaska focused almost entirely on enigmatic hot springs in the Imuruk Basin: the "Pilgrim Hot Springs". The latest studies from 2010-2014 (ACEP, 2015) included drilling 8 new wells to max. depth of 1294 ft and achieving max. temp. of 91°C. But ubiquitous temperature reversals suggested drilling was not directly over the main area of upwelling (Fig. 2). No further development occurred, likely due to the small size of the resource identified at the hot springs location.

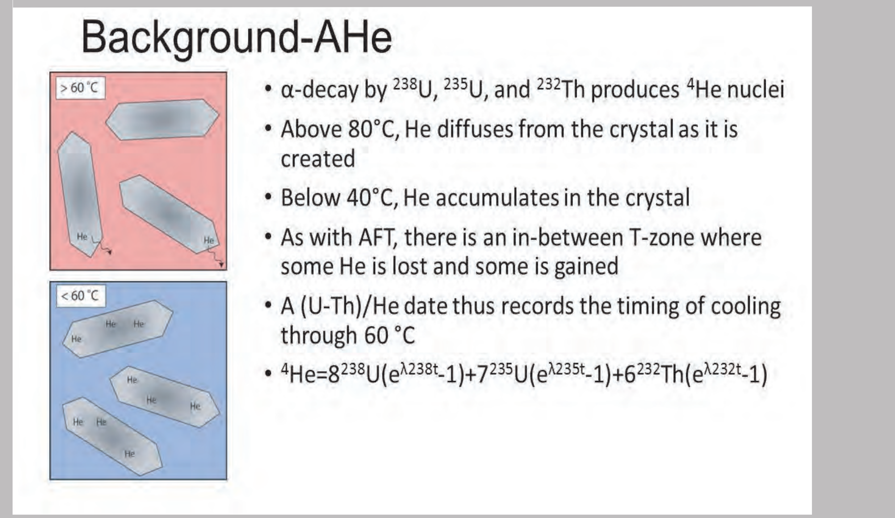
Re-evaluation of the regional data sets by Zanskar Geothermal & Minerals, Inc. (ZGM) suggests the hot springs are surface manifestations of outflow sheets that are many kilometers away from their upwelling source, similar to such occurrences at extensional fault hosted geothermal systems in Nevada (e.g. Coolbaugh et al., 2006). In this model, the active range-bounding extensional fault system is the most permeable structure in the region and thus also likely the location of primary hydrothermal upwelling. Such a model explains the temperature reversals encountered during drilling at Pilgrim Hot Springs and the Na-K-Ca geothermometry of hot spring samples that suggest source temperatures (~145 °C) are much higher than max. temperatures encountered during drilling (91°C) (ACEP, 2015).

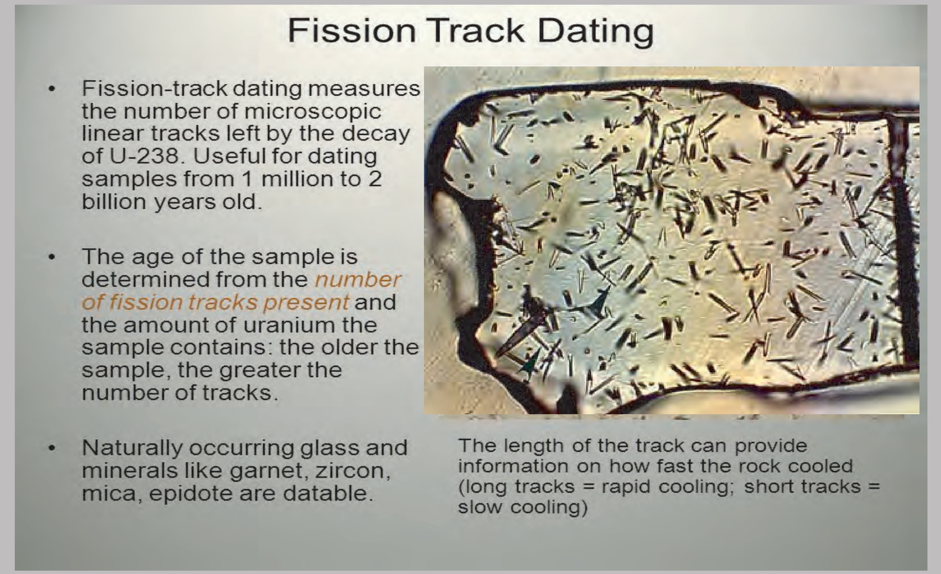
SECOND PHASE OF PROJECT: Low temperature thermochronology – Samples will be collected from bedrock along fault normal transects of the fault and from different segments of the fault with reference to 3D modeling as to the o ptimal orientation for fault-slip generated permeability. Modeling will use the open-source code Beo v.1.0 (Luijendijk, 2019), which allows for simulating the effect of hydrothermal activity on helium concentrations in apatite from surface outcrops. Benefits of this new code package is that it provides a more realistic representation of spring and land surface temperatures compared to models that apply a fixed heat flux, temperature, or transfer coefficient to the surface. Model parameter space will be informed by the 3D geologic model (Phase 1) and iteratively explored to find best fit solutions to the measured sample results, thereby providing constraints on the hydrothermal evolution of the Kigluaik normal fault system. It is expeditious to carry out this work here because we already have data on the time-T evolution of this fault system (Dumitru et al., 1995). This work will be completed in tandem with an exploration campaign planned by Zanskar Geothermal & Minerals, Inc. (ZGM Inc.), on the same active fault system. Potential drilling by ZGM Inc. will allow for an important test of the modeling generated by this research, and serve to validate its applicability to undiscovered resources elsewhere. In addition, we hope to carry out a parallel study on at least one more normal fault system that is optimized for strategic sampling and has a known slip history in the Basin and Range. Because we have worked on so many of these and know their slip rates and cooling histories we can see how the detailed measured T-t profiles along the fault deviate from those within the fault block due to hydrothermal circulation. Where possible, we will collect or reference complementary data sets such as those provided by U-Th-Pb dating of calcite vein materials in faults, apatite fission track ages, length modelling of tracks (~ 100°C) and the He3/He4 low T chronometer.

FIRST PHASE OF PROJECT: Generation of a 3D geologic model (e.g., Siler et al., 2019) that incorporates all available datasets and those provided by ZGM, including new fault mapping informed by photogrammetry, thermal imaging of surficial water bodies, shallow subsurface temperature data, fault slip history constraints from 10Be surface exposure dating and stress state inversions from microseismicity and other local strain indicators. Central and Western Alaska are tectonically complex regions that are deforming today as a result of compression and stress transmission across the state from the plate boundary and intracontinental strike-slip faulting. Strike-slip faulting interacts in a poorly understood fashion with extensional faulting in central and western Alaska; these extensional fault systems are the most likely to host geothermal systems.



Analogous normal faults to the Kigluaik fault are present across the entire Basin and Range province of the western U.S. where they have been studied in detail, particularly in terms of their associated geothermal systems. This example is the Surprise Valley fault studied by Stanford (Lerch et al., 2009) in northwesternmost California. Depending on fault slip rates, hot rocks (T's of~ 300°C) near the ductile-brittle transition zone (DBTZ) in the earth's crust can be moved closer to surface by faulting and provide good geothermal prospects if fluid pathways exist in the faulted rocks.





SUMMARY THOUGHTS: Althought the Earth can provide us with an unlimited supply of heat, commercial-grade geothermal systems are primarily limited by the amount of heat and permeability that can be found at relatively shallow depths in the Earth's crust. Average heat flux is somewhat easy to quantify around the globe, but predicting where permeable pathways are present in the subsurface - which often controls the locations of localized temperature anomalies - is much less straightforward (Siler et al., 2019). It was with the hopes of side-stepping the geological challenge of locating naturally-occuring permeable pathways in the crust that a great deal of government subsidy (e.g. >$100M in US DOE grants since 2000) has been devoted towards engineering permeability in place using technologies that can artificially fracture rocks (i.e. "enhanced geothermal systems", "hot-dry rock"). But due to outstanding challenges in engineered systems (e.g. scaling, induced seismicity, cost), 99.99% of all geothermal power produced today is from naturally occurring systems. Thus, at least in the near term, successful geothermal development depends on identifying naturally occurring systems and to do so, we need a suite of new techniques capable of doing so affordably and effectively, especially in frontier regions.

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