

Evaluation of Observationally Based Models through Saliency and Saliency Maps

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ABSTRACT

Observational scientists use data—either qualitative or quantitative—to construct conceptual models but do not indicate which data are particularly important for the building of that model. We propose the use of saliency to denote the relevance of data in supporting a particular model. Saliency is effectively a weighting factor for observational data with respect to a model. We propose a scale to characterize the saliency of data (from low to high): no attribution, negligible, peripheral, pertinent, important, and paramount. Data that are inconsistent with a given model are categorized with negative saliency values. For fields in which the spatial distribution of saliency can be visually displayed, we introduce the concept of saliency maps. We provide an example of the use of saliency rankings and construction of a saliency map for the Sage Hen Flat pluton in the White Mountains in eastern California. The use of saliency and saliency maps is a way to provide increased reliability and trustworthiness of models, facilitate communication, promote inclusiveness, and allow for scientists to more effectively build off prior data in the observational sciences.

Introduction

Conceptual models are a fundamental method of communication in science. By putting forth testable hypotheses, practitioners can better understand natural processes and explain observed phenomena. Robust models rely on sufficient amounts of high-quality data. Data quality, in turn, can be characterized by the uncertainty in the data. In the Earth sciences, there are multiple efforts to utilize this uncertainty. As an example, uncertainty has been used as a risk management tool for the energy industry (e.g., Rose 2001); in this scenario, significant effort is spent evaluating and quantifying geological uncertainty prior to deciding to drill an expensive well.

Characterizing uncertainty with instrument-based data is quantitative, robust, and well established. For fields that require qualitative observational data, this task is significantly more difficult,

as it requires capturing the uncertainty of the observer. To facilitate recording and communicating uncertainty, the field sciences have started incorporating measures of data quality and uncertainty into their data systems (e.g., Tikoff et al. 2023). Developing community standards for observational data uncertainty opens the opportunity for non-instrumentally collected data to become more reusable and interoperable between various working groups. Given the uncertainty in data and the potential for variation in uncertainty across a dataset, one must have a means of characterizing the robustness of a model. To determine the robustness of a model, a greater understanding of how data are consistent (or not) with a model is required.

In this contribution, we make the case for adding another aspect of information that practitioners can capture, record, and share: saliency. Saliency is a qualitative assessment that characterizes the relationship between data and a specific model. By using saliency, a scientist explicitly evaluates how data influences a model and communicates with

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others how the data were used to develop—or test—a hypothesis. We outline this concept and illustrate its utility by applying it to a geological field area: the Sage Hen Flat pluton in eastern California. We present a salience map of the Sage Hen Flat pluton as an example of how to visually display spatial salience information. Although utilized for bedrock geology in this example, the concept of salience is applicable throughout the Earth sciences and other domains that incorporate inferences from data.

Salience Definition

Salience is defined as “the quality of being particularly noticeable or important; prominence” (Oxford Languages). In the neuro- and cognitive sciences, salience reflects attention to the information in the environment that is pertinent for an organism to learn and survive. Inspired by both definitions, we use the term “salience” to describe the prominence of data with relevance to a particular model. Salient data have functional value; just as salient information is important for an organism to survive, salient data are pertinent for a model to survive, be refined, or be refuted.

This definition has two important implications. First, salience can be either positive or negative. Positive salience indicates the level at which the data are relevant for supporting the model, while negative salience indicates that the data are relevant because they are inconsistent with the proposed model. Second, data can have different levels of salience if utilized by different models; the same data that have high positive salience for one model could have high negative salience for another model. In other words, salience is model dependent.

While recording salience is not currently part of a geological mapping workflow, the concept of salience is already familiar. Field geologists informally refer to the most important locations as “Rosetta” outcrops, in analogy to the Rosetta stone that allowed the translation of Egyptian hieroglyphics. Rosetta outcrops characteristically show critical field relations that aid interpretation of the regional geology and are therefore prime examples of high positive salience data. Current bedrock mapping practice also typically ignores rocks that are clearly not attached to the underlying subsurface (i.e., float), unless there is no exposed rock in a given field area. Such “float mapping” is an example of low-salience data. Taken together, these examples indicate that geologists have an implicit—and generally uncommunicated—knowledge of which are the critical data points that are necessary for a model. That is, they are already characterizing sa-

lience, for at least the end-member categories (e.g., Rosetta and float) of data salience.

By recording salience, geologists are allowed a level of transparent evaluation that is not currently available, providing a description of how the entirety of their datasets fits (positive salience) or not (negative salience) with a model. In doing so, geologists can externalize the mental process of model evaluation. This externalization process allows model development to be a community activity grounded in conversations of salience and facilitates more effective communication of constraints to future practitioners.

Salience diverges from multiple working hypotheses (Gilbert 1877) in that an alternative hypothesis is not necessary to recognize that data are inconsistent with a model. The use of salience provides a way for scientists to record, evaluate, and weigh data that are inconsistent with a particular model. Practically, this process would result in inconsistent data being recorded and less likely to be forgotten, which in turns increases the reliability of the data.

Salience Scale

To fully incorporate salience into the workflow, we must capture gradations in salience on a scale that distinguishes the intermediate categories. Figure 1 shows our proposed scale to characterize the salience of data in supporting (positive salience) or refuting (negative salience) a specific model. The scale ranges from no attribution to paramount, with four broad categories in between. From low to high, the categories are negligible, peripheral, pertinent, and important. These terms are chosen to reflect the judged likelihood that an observation supports or refutes a specific model (respectively less than 25% chance, 25%–50%, 51%–75%, and greater than 75%). The scale is designed to allow people to make stable judgments when using a consistent scale with a limited set of categories (Preston and Coleman 2000).

In practice, the determination of a particular salience value using the scale described above is not just model specific but also dependent on the environment, the practitioner, and timing. For example, when creating a geological map, salience depends on the quality of the outcrop for a specific field area. The simple act of being exposed and attached to the subsurface inherently makes an outcrop important in an area of poor exposure. In contrast, the property of being attached has little relevance in an area of excellent exposure. Field geologists will also differ, based on education, professional background, the

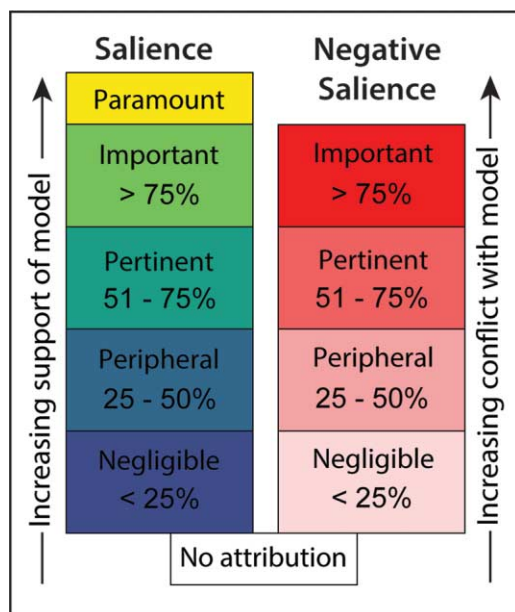


Figure 1. Proposed scale characterizing the salience of data, in support of a specific model (from low to high): no attribution, negligible, peripheral, pertinent, important, and paramount. These terms are chosen to reflect the judged likelihood that an observation supports or refutes a specific model (respectively less than 25% chance, 25%–50%, 51%–75%, and greater than 75%). Note that the negative salience scale does not contain a paramount category, as this type of data would require rejection of a model.

nature of their prior experiences, and association with (or preference for) a model. While this subjective nature of salience is necessary, it is not problematic. All field-based observations are subjective but are trusted because trained observers strive to be consistent with themselves and each other. The same, we argue, will likely be true for the evaluation of the observations (salience) as community standards are developed.

Even with the same geologist mapping the same field area, salience values are dynamic over time and during the course of fieldwork. If working in an area for the first time without a coherent model, it is hard to assign salience values to specific data. However, salience is revisable based on receiving new information and/or conceptually updating the model.

We note that positive salience ranges from no attribution to paramount, although negative salience only ranges from no attribution to important. In our evaluation, if data have paramount negative salience with respect to a model, that model should be considered falsified (e.g., Popper 1959).

Salience values are a means of capturing the interior context of geological decision-making. By externalizing the interior context of model evaluation, scientists can have a shared vocabulary for effective communication of how people weight data in support of a model. Negative salience, in particular, is a useful way to identify the causes of model uncertainty and communicate unresolved questions about a topic or field area.

Below we list the essential elements of salience rankings.

- Salience rankings are a communication tool, documenting how different practitioners weigh data in support of a model.
- A scale is used to characterize the salience of data (from low to high): no attribution, negligible, peripheral, pertinent, important, and paramount.
- The salience of the data is applied in support of a specific model; the same data could have different salience if used to support another model.
- Salience can be positive (consistent or conforming with the proposed model) or negative (inconsistent or nonconforming with the proposed model).
- Salience is revisable, depending on the addition of new data and/or new conceptualizations of the working model(s).
- Salience depends on the context. For example, when creating a geological map, salience depends on the quality/exposure of outcrops for a specific field area.
- Salience rankings may vary across users. Early in the evaluation of a model, observers with differing education, professional background, prior experiences, association with a model, and other factors will likely focus on different facets of a dataset. However, since salience describes a logical consistent relationship between data and model, salience should converge over time.

Salience as the Connection between Data and Models

In the ideal case, a scientific article explains how the data support a model. The finite nature of a scientific article, however, requires that only a small number of arguments are made. The communicated points are selected from the output of the reporting scientist running their conceptual model. Such efforts do not link models to their underlying data in a manner that is complete or unbiased and more typically offers only exemplary data to support the narrative. Many times the results are aggregated (e.g., equal area nets), so information about individual sites is lost. Salience rankings

provide the link to the models and should provide it for the entire dataset rather than a select subset of high-quality data. By linking all data to a model, salience provides transparency on (1) which parts of a field area are important, (2) what data are consistent or inconsistent with a model, and (3) which well-exposed areas were judged to be of lesser or no relevance.

Figure 2 explores how data uncertainty can be tied directly to model uncertainty through salience, using the uncertainty scales of Tikoff et al. (2023). If the data certainty is low (e.g., suggestive), the model certainty will be low regardless of the salience value. Conversely, a high-certainty dataset that has low salience will have low model certainty. Model certainty can be high only if both data certainty is high and the salience of that data is high. Whether large amounts of more uncertain data (e.g., suggestive), if highly salient, could result in lower model uncertainty (e.g., presumptive) remains an open question.

It is interesting to note that experts are the best judges of data certainty that relate to their subdiscipline (e.g., direction of relative motion on faults for a structural geologist). Salience, in contrast, can be evaluated reliably by a larger group of informed practitioners who understand the implications of those data for a specified model. To provide a specific example related to the salience map given be-

low, only an expert who knew the stratigraphy of the White Mountains of California and the lithological variability of the Cambrian Deep Springs Formation could reliably judge the likelihood that the recorded lithology for a station was accurate (data uncertainty). In contrast, a general practitioner could tell you whether knowing the stratigraphic position of a station with a particular rock type (e.g., middle Deep Springs Formation) was relevant to a scientific question (e.g., pluton emplacement of the nearby Jurassic Sage Hen Flat pluton). In this sense, salience allows broader participation in science, utilizing the assessment of expert uncertainty.

Salience Maps

Salience is a tool for communicating how a practitioner weighted field data (both instrumental and observational) in support of a model. To illustrate why this information is needed, consider the relation between data and models in geological maps and cross sections. To create maps, geologists observe and measure rocks exposed at the surface (the data) that are the basis for interpretation of the geometry of the subsurface (the model). Geological maps require interpretation, such as when contacts and lithology are estimated for areas that were not visited or lack sufficient exposure. Cross sections are geometric models built from the interpreted

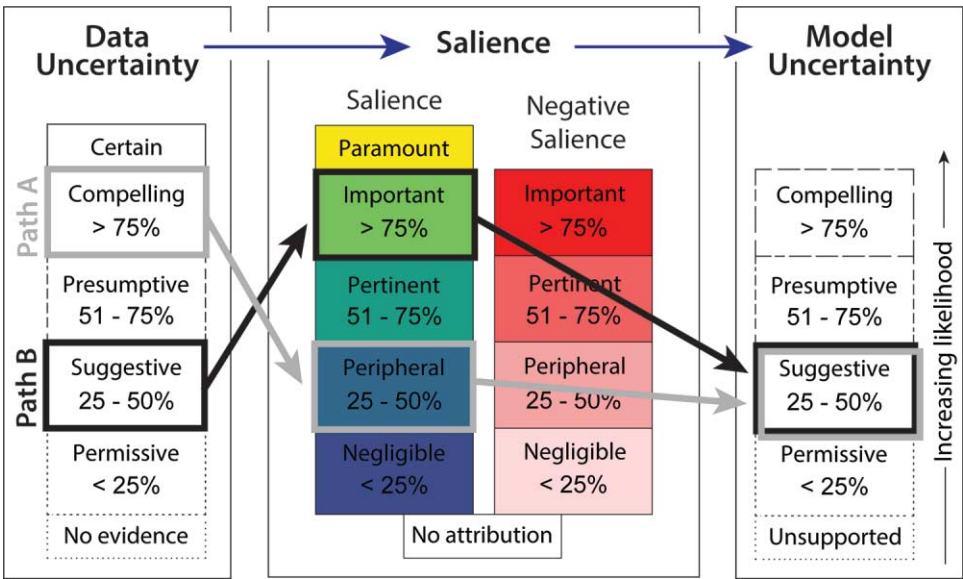


Figure 2. Relation of data uncertainty, salience, and model uncertainty. Shown are two example pathways for a model with suggestive uncertainty. Path A shows a compelling dataset (i.e., >75% chance the observed data is reflective of reality) that is only peripheral to a particular model, therefore decreasing the certainty of the model. Path B shows a suggestive dataset (i.e., 25%–50% chance the observed data is reflective of reality) that is important to a particular model, again preventing the model from having high certainty because it is based on low-certainty data.

surface geology. Furthermore, construction of cross sections may provide feedback for the geological map to guide interpretations of unobserved features, such as contacts and faults. A standard geological map, however, offers few hints as to which are the critical observations that guided construction of the map and cross section.

The concept of salience, in the context of geological mapping, applies to the set of observations made at each outcrop (or part of an outcrop). A salience map characterizes the entire area. It is a construct—built on the same topographic base as the geological map—that spatially identifies the overall importance of data from particular outcrops to the resultant model.

Geologists have already developed additional methods—such as outcrop maps that indicate the extent of exposed attached rock—to increase the utility and accuracy of the geological maps. A comparison of salience maps and outcrop maps is useful because both provide additional information not communicated on typical geological maps. Both types of maps may be plotted as a layer of information on top of a geological map. In typical geological maps, only the presence of structural symbols (e.g., strike and dip) indicate the unambiguous presence of attached rock. Thus, outcrop maps show the location of data from which the extrapolated geological map was created, even if no measurements were taken at that location. Salience maps provide an additional measure of the relevance of those data to the creation of the extrapolated map. Another major difference is that outcrop maps are binary: either rock is exposed in the area or it is not. Salience maps, in contrast, provide a graded quality for each outcrop using the scale introduced above.

Geological Background: Sage Hen Flat, White Mountains, California

We utilize mapping around the Sage Hen Flat pluton of east-central California to illustrate the utility of salience (fig. 3). This section provides a brief geological background for the region, to provide necessary context for the construction of the salience map of the Sage Hen Flat pluton and adjacent regions.

The White-Inyo Mountains are the westernmost range of the Basin and Range Province, immediately east of the Sierra Nevada Mountains. The northern portion of the range (White Mountains) exposes rocks that are chiefly of late Neoproterozoic–Cambrian in age. This passive margin sequence formed on the western edge of North America during Laurentian breakup (e.g., Stevens et al. 1997). The bottom section of this >5-km-thick sequence of

metasedimentary rocks contains, from oldest to youngest, the Wyman Formation, Reed Dolomite, Deep Springs Formation, and Campito Formation (Nelson 1966; Nelson et al. 1991). The metasedimentary rocks contain the gently S-plunging White Mountain anticline. This anticline likely formed during the Permian Sonoma orogeny, associated with movement along the Last Chance thrust fault (Morgan and Law 1998).

Two periods of Mesozoic magmatism—in the Jurassic and Late Cretaceous—affected the White Mountains (Morgan and Law 1998). The Jurassic Sage Hen Flat pluton intrudes into the western limb of the White Mountain anticline. The pluton has a 4-km diameter and an approximately circular exposure pattern in map view. Its composition varies from a hornblende biotite granite to a biotite granodiorite, and it texturally varies from fine to coarse grained (Bilodeau and Nelson 1993). Its emplacement is debated because the pluton does not alter the regional fabric trends of the wall rocks (Morgan et al. 2000). Gravity data indicate that the pluton has a shallow, lens-shaped geometry and does not extend below ~700 m (Nelson et al. 2022). NNW-trending mafic dikes, up to 1 km long, intrude on the western half of the pluton. U-Pb zircon geochronology indicates that the pluton has a crystallization age of 175.4 ± 0.3 Ma (U-Pb zircon; Coleman et al. 2003).

As a part of the Basin and Range Province, the White Mountains experienced Miocene-present extension. The range is bounded by normal faults to the east and west, and there is an eastward tilt of the White Mountain fault block (Stockli et al. 2003; Lee et al. 2009). Normal faults occur locally throughout the range, as determined by offset and tilting of Miocene basalt flows (Krauskopf 1971). Normal faults have not been mapped in the interiors of the plutons of the White Mountains, although they are locally noted at the contacts (e.g., Bilodeau and Nelson 1993).

Salience Map of the Sage Hen Flat Pluton, White Mountains, California

The Sage Hen Flat area was originally chosen because there were two conflicting geological maps and cross sections (fig. 4a, 4b; Ernst and Hall 1987; Bilodeau and Nelson 1993). The geological maps disagree on the west side, and particularly on the northwest corner, of the Sage Hen Flat pluton. The Ernst and Hall (1987) cross section indicates a faulted contact along its western margin of the Sage Hen Flat pluton; the Bilodeau and Nelson (1993) supports intrusive contacts. Tikoff et al. (2023) discussed this situation and noted that quantification

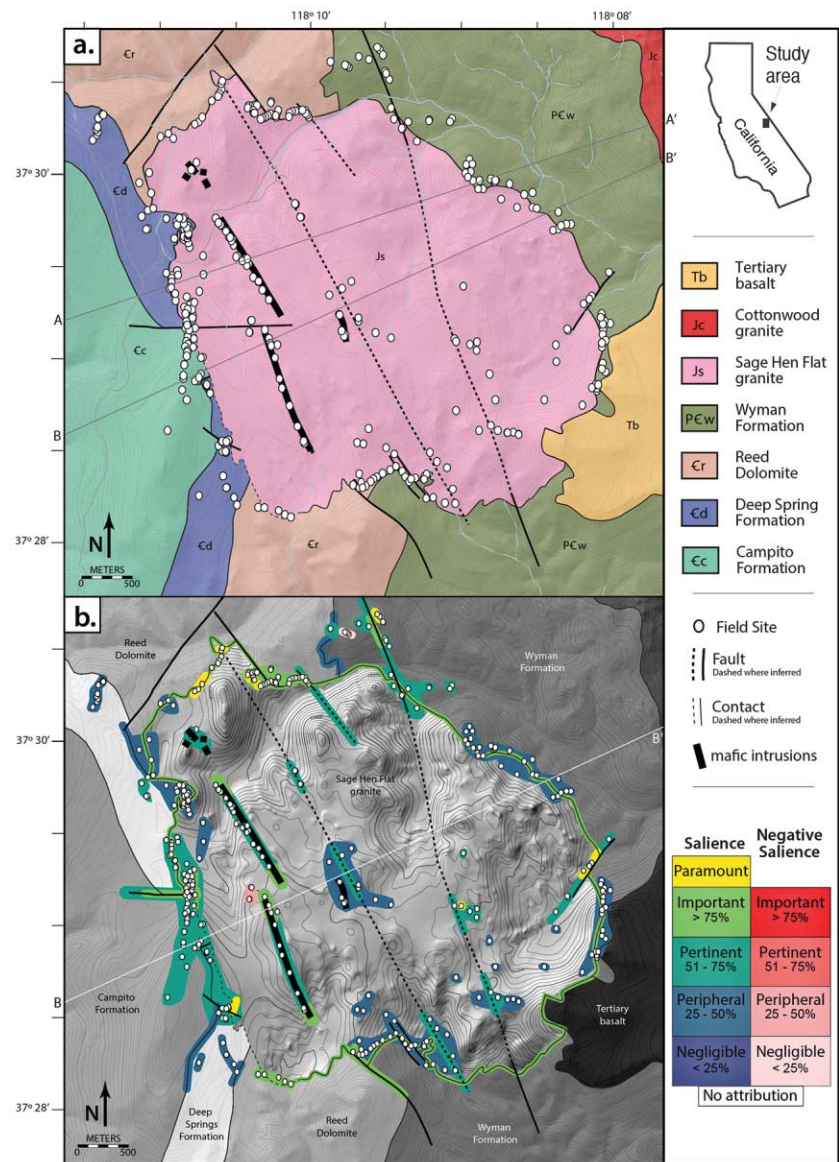


Figure 3. Geological map (a) and salience map (b) for the Sage Hen Flat pluton of east-central California. The geological map is based on mapping by Nelson (1966), Ernst and Hall (1987), Bilodeau and Nelson (1993), and us. The salience map applies to the model—depicted as a cross section—in figure 4c.

of the uncertainty of the data might explain this difference.

While working out how to quantify uncertainty for bedrock field observations in the Sage Hen Flat region—characterized by assigning uncertainty to attachedness, lithology, geometry, and kinematics (Tikoff et al. 2023)—we developed a new model (fig. 4c) for the emplacement of the pluton. This model generally characterizes the pluton contact as intrusive, similar to the Bilodeau and Nelson (1993) model, but contains numerous normal faults affecting the pluton. Normal faults occur locally

throughout the White Mountains but are difficult to recognize in the absence of offset Miocene basalts. Normal faults occur prominently at Tres Plumas peak, located ~4 km north of the Sage Hen Flat pluton (Krauskopf 1971). At that locality, Miocene basalts show tens of meters of dip-slip offset and a gentle eastward dip, consistent with displacement by normal faults. These normal faults, if projected on strike, intersect the Sage Hen Flat pluton. Furthermore, basalt flows on the east side of the Sage Hen Flat pluton also have a shallow eastward dip, similar to those at the Tres Plumas peak. The

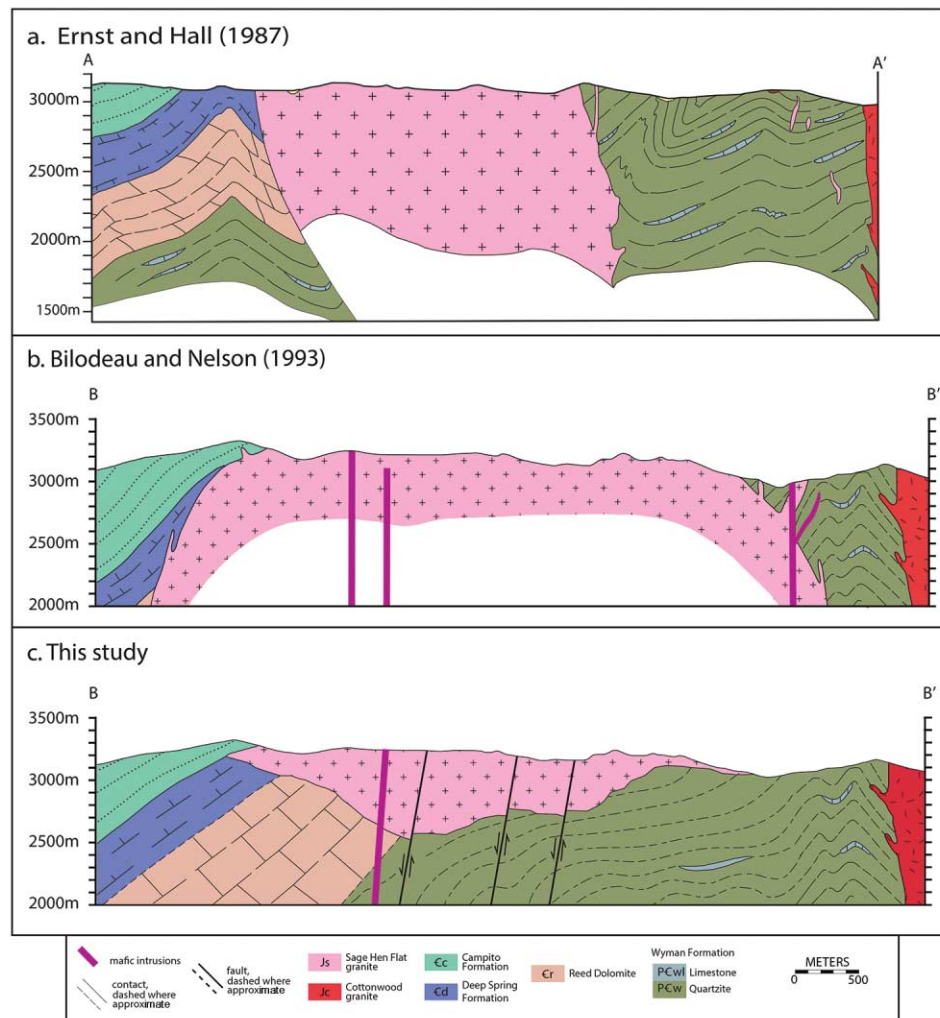


Figure 4. Three ENE-oriented cross sections, each of which records a different subsurface geometry for the Sage Hen pluton. *a*, Ernst and Hall (1987). *b*, Bilodeau and Nelson (1993). *c*, Our model. The scale and legend are the same for all cross sections.

evidence for the normal faults exposed within the Sage Hen Flat pluton is based on the presence of (1) springs along linear arrays (shown on topographic maps of the area), (2) geomorphic low points—including saddles on ridges—that form linear arrays, (3) outcrops with increased fracturing and faulting along these trends, and (4) local occurrences of fault breccia along the trends, although occurring exclusively as unattached float.

The salience map of the Sage Hen Flat pluton—for our model only—is shown in figure 3*b*. Each outcrop is assigned a salience value for its support of our model. Because the geological map and the salience map are best observed together, we have plotted the salience values directly on top of the geological map. The salience map shows the pattern of our work—focused on the circular outline

of the pluton and the relatively straight trends of the suspect faults that transect the field area—was strongly dependent on the quality of the prior mapping. We focused on the contact of the pluton because of its relevance for our model, but also because it is one of the best markers from which to judge fault offset.

The general guide for applying the salience scale in the field was the question, How much would it matter if this outcrop disappeared? If the answer was that an outcrop was critical to understanding the area, it was given an “important” ranking. If the outcrop was unique in what it displayed and that information was critical for the model, it was given a “paramount” rating. If the disappearance of the outcrop would have no effect on the model, it was given a low ranking.

Consider the hypothetical example of an exposed fault at Sage Hen Flat pluton. Exposed, large-offset faults with clear fault rocks (e.g., breccia, gouge) are relatively rare in this environment. If one such outcrop occurred, it would have paramount salience. If, in contrast, there were three such exposures along a single fault, each one would be important, but none would be paramount.

The yellow-green spectrum is used to highlight positive salience (fig. 3*b*). The highest-value yellow points occur where we could directly constrain the presence of the faults within the pluton or at the margin of the pluton. We also noticed the tendency for high-salience regions to be locations where we, as practitioners, collected more data. In other words, high-salience regions—such as a highly faulted outcrop within the pluton—typically coincide with more measurements, photos, and notes compared with relatively low-salience outcrops—such as a homogenous, unfractured granitic outcrop. The low-salience outcrops for this field area were either (1) granitic outcrop in the middle of the pluton that did not show any evidence of faulting or (2) wall-rock outcrops away from all contacts and faults.

We also mapped areas of negative salience, plotted on the pink-red spectrum. At this location, we noted the presence of outcrop-scale ~EW-striking faults. We did not map any fault at that location, and hence those data are inconsistent with our mapping. If those faults had dextral strike-slip movement, it might also explain the apparent dextral offset of a prominent basaltic dike that occurs within the pluton. We highlight this negative salience because of its utility as a communication tool to future workers for identifying unresolved issues.

Our salience rankings changed as our model was replaced, modified, and refined. Once included as part of a published article, however, the salience rankings (and the associated salience map) become fixed with respect to the published model. We constructed multiple “working” salience maps during the course of the fieldwork, to determine its efficacy. In the end, the creation of multiple working salience maps did capture the evolution of our model generation, but we do not necessarily advocate this approach for typical scientific work. We think it is sufficient for practitioners to produce a single salience map once they have considered all of the data.

Discussion

Applying Salience to Models. Salience ratings—and their amalgamation into salience maps—are a way of characterizing how much a given observation

(or a small set of observations) supports or refutes an idea. The ratings themselves are necessarily subjective. If we were working on another aspect of the geology in the White Mountains (e.g., regional deformation, stratigraphy), our salience map would be different. If salience maps were available from the previous work by Ernst and Hall (1987) or Bilodeau and Nelson (1993), they would likely look different from each other and from our salience map. Hence, the attribution of salience captures the essential elements of the process of science without requiring uniformity of approach or a specific protocol.

A fundamental aspect of salience is that it allows articulation of different models, despite the fact that the models might be incorrect. For example, we do not know whether we are correct in our interpretation of the significance of normal faults on Sage Hen Flat. However, our field strategy and our salience ratings are tied explicitly to the presence or absence of those faults.

We were drawn to the Sage Hen Flat pluton area because of the disagreement of the previous interpretations. This scientific controversy, as well as others observed by the authors, highlights that geologists are consciously or subconsciously ranking data. When a field-based controversy arises, proponents of one model typically will show you one set of outcrops, while those supporting another model may show you a different set of outcrops. In this example, the geologists are inherently disagreeing on the salience of specific outcrops. Making these differences as explicit as possible, using salience rankings, is an expedient approach to facilitate future models by future practitioners.

We did not produce salience maps for either the Ernst and Hall (1987) model or the Bilodeau and Nelson (1993) model for multiple reasons. First, we would not be able to provide unbiased evaluations of the other models relative to our model. Second, our new model was informed by additional information (e.g., gravity and magnetic data) that the earlier mappers did not have. Thus, the comparison would be unfair. Third, despite having some strike and dip information, we do not know where the other mappers collected data. Finally, we cannot accurately assess the previous authors' views of the salience of particular outcrops. Consequently, making a salience map for the earlier work would be speculative at best.

It is worth noting that salience maps—as we have articulated them—are mostly associated with empirical science. The inverse of salience maps does exist for theoretical approaches. Modelers—particularly in hydrogeology—have used quantitative models to predict where high-impact data can be

collected. For example, Tiedeman et al. (2003, 2004) made an explicit forecast of a model linked to data collection.

Salience as a Tool for Communication and Inclusiveness. Salience ratings are, at their core, a means of communication. To our knowledge, there is no record in the geological literature of previous attempts to systematically characterize the importance of specific data to models. In part, this situation arose from the reliance of physical paper copies of manuscripts. The ability to utilize digital databases (e.g., StraboSpot; Walker et al. 2019) allows the community to move beyond the current limitations of reporting based on static paper copies and to record new types of data, including salience. This use of digital technologies will improve the mental process of model creation and evaluation by externalizing it and communicating it to other practitioners, present and future.

Field trips—either formal or informal—are a common venue in which experts explicitly discuss the connection between observations and models. The value, often unstated, of articulating how observations support or do not support models explains the prevalence of the field trip as a means of professional communication. Most field trips are designed to take visitors to both well-exposed and scientifically important (or paramount) outcrops within a field area. Pictures of these high-salience outcrops typically make it into peer-reviewed publications and field guides. These field trips, however, provide only a partial view of the field area. Most field areas are not easily accessible by a group, and moreover there is rarely enough time to see all of the important features of a field area.

Mapping salience allows access to the detailed relationship between data and models in a field site without physically visiting the area. Only by characterizing an entire field area do you make a study fully accessible. In this sense, salience rankings will never replace field trips, but they are a complementary feature providing a communication to a wider community of users and details of the entire field area.

An unexpected outcome of salience, in the context of the above paragraphs, is its capacity to promote inclusivity. Much of the discussion about data quality and what data imperfectly fit a current model occurs in informal settings such as field trips. While field trips—particularly when supported by professional societies (e.g., the Geological Society of America)—are open to all members, they contain barriers to participation (e.g., cost, physical ability, time). Mapping salience allows a new level of professional communication for those who are not able

to personally discuss the field area with the people most familiar with it.

Salience Allows Better Observational Science. Observational sciences must build models from limited observations, from which theoretically important processes and/or parameters are rarely isolated. A threat to such science is the potential for bias to restrict what data are collected and what data are shared. Salience reduces the concern by highlighting for other scientists both where critical observations can be confirmed and where additional valuable data might be collected.

Replication. The use of salience rankings can partially overcome the problem associated with the concept of reproducibility for the observational sciences. First, a salience map is a tool for doing science by inviting replication. It identifies places that are particularly important to a model, thereby inviting others to seek out those places. This feature alone is a significant improvement to reproducibility in the field-based sciences. Second, a salience map provides information for where bias might be a problem (see “The Role of Negative Salience” below). That is, it provides a communication mechanism for where the scientist went and how important that person thought the data were from that point. Third, salience forces one to prioritize data over models; it is the data that have the salience ranking, not the model.

The Role of Negative Salience. There are multiple reasons to use negative salience values. First, some data are likely incorrect. Second, some data are inherently confusing. Third, nonconforming observations are important for multiple reasons. In some cases, they become “the exception that proves the rule” (or as better expressed, “the exception [that] probes the rule by testing and exploring the consequences in altered situations”; Gould 1972, p. 72). In other cases, negative salience values highlight that a model is an imperfect representation of a particular area. These types of observations are rarely highlighted in professional articles but could identify critical areas for future workers to visit to improve the model(s). Fourth, the potential for negative salience values emphasizes that the data are inherently more valuable than the model. High-quality data typically last longer than high-quality models in the literature. If the point is to facilitate future models and future practitioners, then it is expedient to provide them with as much information as possible.

Negative salience may prove to be the most useful of the salience rankings. A negative salience value might arise from a simple error, such as interpreting a rock as attached although it is not, and

thus its spatial properties are unrelated to the surrounding rocks. Alternatively, negative salience might provide a more serious indication of an inconsistency with a model. If these negative salience values accumulate, it provides an impetus to revisit both the field area and the model.

The use of negative salience provides a mechanism that is currently unavailable, which allows for more transparency on the part of the scientists. Most scientists know there are observations that do not fully fit their model; most are willing to communicate that information to others in informal settings (e.g., field trips). During the course of the publication review process, negative salience might be added to a salience map when an external reviewer informs the authors of inconsistent data. The negative salience rankings are a way of linking the resultant model back to the data and communicating that information clearly to future researchers. The larger the negative salience, the greater the opportunity to construct a better model. The ability to include negative salience will facilitate more trust for data—particularly digital data—within the community.

Workflow. Salience and salience maps may fundamentally change our workflow. Because salience communicates relevance, future workers can quickly establish to what extent they agree with prior workers. In the case of high agreement, future workers can utilize the prior data efficiently. That is, practitioners may seek out a salience map to see where the prior workers think the model could be improved.

The Earth science community has focused on FAIR (findable, accessible, interoperable, and reusable) standards for its digital repositories. This approach—and the importance of metadata to allow the above—are the necessary requirements to utilize data collected by others. As the field enters this new digital era, there is an opportunity to develop workflows that recognize the value of recording how experts were reasoning as they collected data and developed their accounts of a region. Recording salience is one of those opportunities.

Salience as Linking Data. Salience is a new type of data, which we refer to as “linking data.” Salience is attributed to the data, although it is specific to a particular model. If one utilized the method of multiple working hypotheses, each station could have multiple salience rankings. In practical terms, salience is likely to be stored as mutable metadata (metadata that are changeable), but it would also need to explicitly indicate the model to which it applies.

We note that the salience, gathered at the moment of data collection (working salience), might be

informative about the biases present in the observer. How to use salience to reduce the influence of bias on models is an open question for future work. It is possible, however, that the act of articulating salience itself is an effective way to reduce bias, similar to other approaches to reducing bias (e.g., Macrae et al. 2016). A visualization that highlights both consistent data and inconsistent data will increase the chance of considering inconsistent data in the overall evaluation of a model and thereby reduce confirmation bias. Regardless, the use of salience allows us to move beyond the current limitations of reporting based on static paper copies and more fully embrace digital technologies to enhance professional practice. Through its use, we can improve the mental processes of model creation, evaluation by externalizing it, and communicating it to present and future practitioners.

Conclusions

We propose the adoption of salience rankings into the geological workflow. Salience acts as a “weighting factor” for a particular observation with respect to a particular model. Furthermore, it provides the tools for practitioners to communicate the importance of all data in a given study area, not just the publication-worthy “Rosetta” outcrops. Salience is characterized using a scale to designate the salience of data in supporting a specific model. From low to high, these are as follows: no attribution, negligible, peripheral, pertinent, important, and paramount. Data can have either positive salience, if they support a model, or negative salience, if they are not consistent with a model. A salience value is model dependent and subject to revision.

We provide an example salience map for the Sage Hen Flat pluton, White Mountains, eastern California. The salience map for the Sage Hen Flat pluton characterizes how much a given outcrop influenced the building of the model. As such, it is a communication tool for future workers both to understand the approach taken to build a particular model and to locate outcrops that might lead to new insights. Negative salience values are particularly useful in this regard. Salience maps are also a tool for inclusivity because they do not require personal interaction with the geologist who mapped the area or that one is physically able to visit the area. Finally, the use of salience also externalizes the mental process of model evaluation. The explicit characterization of salience—and its visual manifestation in salience maps—will fundamentally improve the process and quality of observational science.

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