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ARTICLE

X-Ray Fluorescence Spectrometry as a Cultural Resource Management Tool

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Abstract
Energy-dispersive X-ray fluorescence (XRF) spectrometry is commonly used by archaeologists and museum staff to nondestructively characterize the elemental composition of artifacts or other materials of cultural relevance, ranging from obsidian and other lithics, to soils, pigments, metals, ceramics, and brick. However, to date, it is primarily viewed as an academic research tool. In contrast, this article demonstrates how XRF can be adopted by cultural resource management (CRM) professionals and effectively integrated into National Historic Preservation Act compliance in the United States. Two case studies from the Idaho National Laboratory and Nellis Air Force Base, Nevada, are discussed that provide examples of how the technology has been applied to the analysis of a range of materials and integrated into Section 106 decision-making processes that include site characterization, National Register of Historic Places eligibility recommendations, and preservation efforts. At its core, the integration of XRF analysis fosters efficiencies that enhance methodological transparency, support noncollection policies, and promote shared understandings between an agency, a State Historic Preservation Office, Tribes, and stakeholders. We hope that these discussions lead to increased representation of XRF among CRM professionals across federal and state agencies and private CRM firms.

Resumen
La espectrometría de fluorescencia de rayos X (XRF) de dispersión de energía es utilizada habitualmente por arqueólogos y personal de museos para caracterizar de forma no destructiva la composición elemental de artefactos u otros materiales de relevancia cultural, tales como obsidiana y otros materiales líticos, suelos, pigmentos, metales, cerámicas y ladrillos. Sin embargo, hasta la fecha se considera principalmente una herramienta de investigación académica. En contraste, este artículo demuestra cómo los profesionales de la administración de recursos culturales pueden adoptar la XRF e integrarla eficazmente en el cumplimiento de la Ley Nacional de Preservación Histórica (NHPA) en los Estados Unidos. Se analizan dos casos de estudio, correspondientes al Laboratorio Nacional de Idaho (INL) y a la Base de la Fuerza Aérea Nellis (NAFB) en Nevada, que proporciona ejemplos respeto a cómo se ha aplicado la tecnología al análisis de diversos materiales e integrado en los procesos de toma de decisiones de la Sección 106, los cuales incluyen la caracterización de los sitios, las recomendaciones sobre de la elegibilidad para el Registro Nacional de Lugares Históricos e iniciativas de preservación. En esencia, la integración del análisis por XRF fomenta las eficiencias que mejoran la transparencia metodológica, respaldan las normativas de no recolección, y promueven una comprensión compartida entre una agencia, la Oficina Estatal de Preservación Histórica, los grupos indígenas y otras partes interesadas. Esperamos que estas discusiones contribuyan a una mayor representación de la XRF en el trabajo de los profesionales del CRM de agencias federales y estatales, así como de empresas privadas de CRM.

Keywords: cultural resource management (CRM); Idaho National Laboratory (INL); National Historic Preservation Act (NHPA); Nellis Air Force Base (NAFB); X-ray fluorescence (XRF) spectrometry

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Palabras clave: gestión de recursos culturales; Laboratorio Nacional de Idaho; Ley Nacional para la Conservación Histórica; Base de Nellis de la Fuerza Aérea; espectrometría de fluorescencia de rayos X (XRF)

The goal of this article is to demonstrate how energy-dispersive X-ray fluorescence (XRF) spectrometry can be used as an effective cultural resource management (CRM) tool for National Historic Preservation Act (NHPA) compliance. Two case studies from the Idaho National Laboratory (INL) and Nellis Air Force Base (NAFB), Nevada, provide examples of how the technology has been applied to the analysis of a range of archaeological and geological materials and in turn integrated into Section 106 decision-making processes that include site characterization, National Register of Historic Places (NRHP) eligibility recommendations, and preservation efforts (Figure 1). We hope that these discussions lead to increased representation of XRF among CRM professionals across federal and state agencies and private CRM firms and can be used as a practical guide to justify the purchase of instrumentation.

Numerous publications exist on the technical aspects of XRF, which are beyond the scope of the current article, but at the heart of XRF technology is the principle that primary X-rays shot at a sample create vacancies in the atoms on the surface of the material that produce secondary, or fluorescent, X-rays characteristic of its elemental composition (see Drake and MacDonald 2022; Potts and West 2008; Shackley 2011). XRF has advantages and limitations, and it is not appropriate for all types of elemental analysis, but its portability, relative rapidity, and cost-effectiveness make it ideally suited to address a range of archaeological issues (Frahm 2024; Freund 2013; Liritzis and Zacharias 2011; Tykot 2016). A great deal of attention has been paid by archaeologists to the technical aspects of XRF, including the accuracy of XRF data output and the importance of proper calibration protocols (Acquafredda 2019; Frahm 2013; Frahm et al. 2022; Johnson et al. 2021, 2024; Shackley 2011; Speakman and Shackley 2013), as well as differences between portable and benchtop XRF instrumentation (Goodale et al. 2012; Liritzis and Zacharias 2011) and associated comparisons with other analytical techniques (see Glascock 2011). The goal here is not to rehash these discussions but rather to stress that at a minimum an instrument should utilize proper calibration protocols and be optimized for the materials being analyzed. Proper instrument setup can typically be achieved by working with the manufacturer of the purchased instrument, but users should be aware of the limitations of XRF in analyzing certain media and know the types of archaeological questions and issues XRF can be used to address.

XRF is used by archaeologists to nondestructively characterize the elemental composition of artifacts or other materials of cultural relevance. In the western United States, it is most often applied to lithic provenance and typically involves matching obsidian artifacts found at archaeological sites to the geological deposits from which they were collected (see Duke et al. 2025; Freund et al. 2022; Hughes 2018; Jones et al. 2012; O'Shea et al. 2021; Shackley 2021; Smith et al. 2024). In contrast, using XRF to analyze ceramic and brick artifacts has typically centered on identifying distinct geochemical groups within an assemblage, although matching ceramic artifacts to geological clay sources is also possible (e.g., Finnigan and Golitko 2023; Frahm 2018; Ownby 2012; Tykot et al. 2013). Nevertheless, XRF analysis of ceramics is not without its limitations, because pottery is an inherently heterogeneous class of artifact and XRF is a surface analysis that does not consider elemental variability across an entire sherd or vessel (for further discussion see Holmqvist 2017; Hunt and Speakman 2015).

Over the past two to three decades, XRF instruments—and portable units in particular—have become widely available and been readily adopted across academia (Drake and MacDonald 2022; Shackley 2020; Tykot 2016). However, their incorporation among CRM professionals has been less consistent. For example, in a recently published compendium by Drake and MacDonald (2022) on *Advances in Portable X-ray Fluorescence Spectrometry*, CRM archaeology is barely mentioned. Nevertheless, the technology has been embraced by major CRM firms in the western United States, where obsidian is ubiquitous across many archaeological contexts, and obsidian-sourcing has become a routine component of archaeological survey and excavation. Historically, these types of studies have been driven by a handful of commercial laboratories, but studies of this type necessitate artifact collection, and costs inherently limit the number of objects that can be analyzed. Here, we argue that CRM professionals can effectively integrate XRF technology into their Section 106 processes in ways that extend beyond sending small numbers of artifacts to specialists. In contrast, it can be integrated into a CRM strategy that

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Figure 1. Locations of the Idaho National Laboratory (INL) Site, Nellis Air Force Base (NAFB), Nevada, and the Nevada Test and Training Range (NTTR).

sees XRF not just as a research tool but as a management tool that can support an organization's mission and foster efficiencies, including

- noncollection policies that leave cultural objects in situ
- supplementary methods for site characterization
- more informed NRHP eligibility recommendations
- alternative data recovery and mitigation strategies
- improved preservation efforts

These efficiencies enhance methodological transparency and promote shared understandings of decision-making processes between agencies, State Historic Preservation Offices (SHPOs), Tribes, and stakeholders.

Background to the NHPA

In the United States, archaeological sites and other cultural resources are primarily managed under the provisions of the NHPA (for more thorough reviews, see King 2016, 2020). The NHPA was passed in 1966 with the goal of establishing a national preservation policy to protect historical and cultural heritage, in turn creating the NRHP and requiring federal agencies to evaluate how their projects

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impact archaeological and historical sites. The NHPA requires federal agencies to consult with appropriate stakeholders who have vested interests in federal undertakings, which can involve SHPOs, Tribal partners, local governments, and/or the public.

Section 106 is a core component of the NHPA that requires federal agencies to consider the effects of their undertakings on historic properties, and if a project has the potential to affect buildings, structures, objects, districts, or archaeological sites that are listed or eligible for listing in the NRHP, then a thorough review will take place. Identifying archaeological properties and assessing their eligibility for listing in the NRHP thus becomes a key component of compliance archaeology in the United States. Section 110 of the NHPA works in concert with Section 106, setting out the broad historic preservation responsibilities of federal agencies and calling on these agencies to establish their own preservation programs for the identification, evaluation, and protection of historic properties.

XRF analyses of archaeological materials are often seen by CRM archaeologists as falling under the purview of Section 110; that is, research that contributes to a broader preservation program but is not directly integrated into Section 106 workflows. However, we hope that the following examples demonstrate how XRF can be effectively integrated into Section 106 decision-making processes that greatly expand the relevance of the technology in CRM archaeology and highlight how Sections 106 and 110 can work together to ensure the highest standards of quality and efficiency.

Importance of Context

While there is clear utility to XRF technology, its interpretive remit is only as powerful as the framework within which it is contextualized. For compliance archaeology, context documents provide the foundation for agency decisions in the identification, evaluation, and treatment of historic properties, and can manifest as formal historic contexts, cultural resource management plans (CRMPs), integrated CRMPs (ICRMPs), or internal guiding documents.

The Secretary of the Interior's (1983) "Standards and Guidelines for Archaeology and Historic Preservation" provides details on the development of historic context documents designed to facilitate the management of cultural resources. Historic contexts describe the significant broad patterns of history that may be represented by cultural properties within an area and identify important themes and associated research questions that tie directly to the NRHP evaluation of these properties. Defining the kinds of properties expected within a study area and grouping them into the property types most useful for representing important historic trends thus allows for more nuanced assessments of site function and integrity and serves to significantly enhance NRHP eligibility recommendations. As demonstrated by the two case studies in this article, XRF is a useful tool that can be integrated into this process and can be applied to archaeological site characterization, NRHP evaluations, and preservation efforts.

For many federal and state agencies, a CRMP or ICRMP is the primary guiding document outlining the mission and scope of a cultural resources program. In lieu of a formal historic context, a CRMP will often outline the archaeological history of an administered area and provide guidance on the evaluation of cultural resources that are likely to be encountered. Many agencies, however, rely on context documents that do not consider the use of XRF or the results of provenance research, and in these circumstances standalone reports or studies can serve a similar purpose (e.g., Haarklau et al. 2005). Within these documents, there is room to highlight significant themes and research questions that can be applied to NRHP eligibility recommendations.

When and How Should It Be Used

This section details the ways in which XRF analysis can be practically applied to common Section 106 processes, including archaeological site characterization, NRHP evaluations, and preservation efforts.

Site Characterization

XRF is nondestructive, and portable units can be used in the field, representing an effective tool for defining property types, maximizing the data potential of an archaeological site, and situating it within its historical context, all while eliminating the need for artifact collection and curation. As such, XRF analysis facilitates the interpretation of a site, which, against the background of prior data, allows for

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a more informed assessment of the site's significance. Specialized analyses such as radiocarbon dating or XRF complement background research using archival materials, oral histories, ethnohistories, and the archaeological literature, all of which contribute to establishing the significance of a property. Such robust site characterization is key to compiling archaeological site forms and associated descriptions, as well as making informed management decisions.

In practical terms, XRF analysis of artifacts from a range of archaeological sites across an area can establish a baseline of expectations for the types of artifacts anticipated to be found at a particular property type. In the case of obsidian, this would comprise the geological sources one would expect to find in a particular lithic assemblage, depending on site function, or in the case of ceramics, this would consist of the compositional groups under which one would expect ceramic sherds to fall. Site characterization, through consistent and repeated analyses, can reveal broader patterns of diachronic and spatial variability within which archaeological sites can be situated and NRHP evaluations can be based.

Evaluation of NRHP Eligibility

According to the *National Register Bulletin Guidelines for Evaluating and Registering Archaeological Properties* (Little et al. 2000), the first step to evaluating the NRHP eligibility of an archaeological site is defining its function or role and situating it within defined property types. The next step is identifying which of the four NRHP criteria would apply and determining how integrity would be evaluated under each criterion. With specific reference to Criterion D, NRHP significance relates directly to the research questions and themes defined within an organization's context documents and to determining whether the property has the data requirements necessary to answer—or make a substantial contribution to answering—such questions. When XRF is consistently used as a site characterization tool, NRHP significance can readily be contextualized within known or predicted patterns of procurement, conveyance, or discard. Indeed, combining XRF analysis with techno-typological considerations that evaluate data from multiple stages of artifact life histories represents a meaningful approach to assessing the significance of an archaeological property.

Additionally, when adverse effects to archaeological sites eligible for listing in the NRHP under Criterion D cannot be avoided or minimized, they are often mitigated through data recovery in accordance with an agreed-upon treatment plan. Analytical techniques such as radiocarbon dating and XRF can be crucial components of data recovery for sites with materials amenable to those approaches.

Preservation

XRF can be an effective component of archaeological preservation (Liss and Stout 2017; Quinn 2022; Shugar and Mass 2012). For example, it can be used to identify and match pigments used in paintings or pictographs (Bow et al. 2025; Cesario et al. 2022); characterize the metal alloy content of jewelry, coins, weaponry, or silverware (Dussubieux and Walder 2015; Selinsky 2023); or identify the source and composition of construction materials such as brick or mortar (Finnigan and Golitko 2023; Leone et al. 2016; Pink and Freund 2026), all of which can aid in preservation and provide a basis for restoration efforts where materials need to be as compatible as possible with existing media.

XRF can also be used to identify how objects may have been preserved in the past or are deteriorating in the present, thus providing the necessary knowledge to better conserve them for the future (Barrett et al. 2012; Shugar and Sirois 2012). For example, a study of bricks from the Punta Begoña Galleries in Getxo, Spain, revealed that brick deterioration was directly related to exposure to marine environments, and the industrial port of Bilbao in particular, as well as associated proximity to nearby factories emitting atmospheric pollutants (Morillas et al. 2018).

Case Study 1: INL, Idaho

The INL Site is a complex of federal nuclear research facilities that occupies 2,305 km^2 of land on the Eastern Snake River Plain of eastern Idaho, within the traditional territory of the Northern Shoshone and Bannock peoples. The INL Cultural Resource Management Office (CRMO) XRF Laboratory specializes in analyzing archaeological and geological materials using XRF. Materials analyzed at the lab

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Figure 2. In-field XRF analysis at the Idaho National Laboratory (photo by Jeremias M. Pink).

include obsidian and other fine-grained volcanics (FGV), ceramics, and brick. XRF equipment includes two Olympus Vanta M Series portable XRF spectrometers equipped with 4-watt X-ray tubes, rhodium anodes, and 40 mm^2 silicon drift detectors.

For the INL CRMO, the eastern Idaho Precontact Context (PCC) is a formal historic context document that represents an organizational framework for the identification and evaluation of precontact archaeological resources in eastern Idaho (Idaho National Laboratory Cultural Resource Management Office [INL CRMO] 2026). The PCC encompasses a study area of approximately 6 million ha, with an understanding that the significance of archaeological resources on the INL can only be understood within a broader geographic and regional context. Consultation with the Shoshone-Bannock Tribes is central to CRM at INL, and Tribal partners are regularly and actively involved in survey, site recordation, artifact analysis, and evaluation. The Tribes have been particularly receptive to XRF analyses because they are nondestructive and can be undertaken in the field without the need for artifact collection (Figure 2). The resulting data have fostered communication and become a shared touchpoint for interpretation.

Lithic and Ceramic Analysis for Site Characterization and NRHP Eligibility

Obsidian and FGV

Most archaeological sites on the Eastern Snake River Plain of Idaho are surficial lithic scatters that represent open exposures of lithic tools and debris reflecting episodes of past occupation by mobile groups. The majority of such sites have little potential for intact stratigraphy or subsurface deposits but vary greatly in size as well as in the quantity and diversity of artifacts evident on the surface. Their lithic assemblages tend to be dominated by obsidian, reflecting the widespread availability of the material in southern Idaho.

As part of the PCC, XRF analysis was conducted on 2,338 obsidian and FGV projectile points from 876 archaeological sites across eastern Idaho (INL CRMO 2026). Source determinations were made through statistical comparison with a comprehensive reference library of Idaho geologic obsidian and

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FGV that currently contains 30 compositional reference groups (sources) of obsidian and five reference groups of FGV defined through XRF analysis of over 2,700 geological samples from 226 sampling locations (Freund, Pink, and Clements 2026; Pink 2025a).

The PCC XRF dataset provides a diachronic but generalized regional view of source use at the INL Site and across eastern Idaho, establishing a robust baseline for evaluations of lithic resource use at individual sites. Specifically, this work reveals a broad consistency in source use at the INL Site from the Early Holocene onward, with just three sources (Bear Gulch, Big Southern Butte, and Walcott Tuff) comprising as much as 75% of projectile points in certain periods, and the remainder derived from more distant sources throughout southern Idaho. These findings help define expectations for and contextualize source use at the site level among common property types such as seasonal base camps and field camps.

Building on these analyses, more recent efforts have focused on implementing in-field XRF to assess source use at individual archaeological sites with relatively intact and complete assemblages. The goal is not to analyze every artifact from every site, nor is it to only focus on projectile points, which can bias a sample, but to analyze artifacts across multiple lithic classes (e.g., debitage, flake tools, projectile points, etc.) with differential degrees of investment and potential for curation. Results thus far have revealed remarkable differences in the distance, diversity, and directionality of source use among individual sites and artifact classes (Pink 2025b) that often contrast sharply with generalized patterns of source use at the regional scale. In this way, in-field XRF offers the potential to reveal novel and substantive data on aspects of site function, lithic provisioning, and seasonal mobility at specific locales through the analysis of multiple artifact classes (Pink 2025b).

These efforts align with significant research themes and questions outlined in the PCC, including most notably the themes of "Settlement and Subsistence" and "Technology, Adaptive Strategies, and Mobility" and attendant research questions that can be addressed using XRF (INL CRMO 2026). Beyond questions concerning the dynamics between generalized versus site-level source representation, other relevant research questions that can be addressed using XRF include

- What can single-component manufacturing sites reveal about technological traditions, and how do these traditions of production compare with other regions outside of eastern Idaho?
- How do procurement strategies differ between various lithic raw materials (e.g., obsidian, FGV, chert, etc.) in eastern Idaho?
- How did patterns of mobility and land use change after Shoshonean bands acquired the horse in the late seventeenth and eighteenth centuries AD?
- To what extent were people in eastern Idaho connected to groups from outside the region during the Late Holocene (e.g., Fremont and Columbia Plateau communities)?

Ceramics

Ceramic analysis using XRF is a burgeoning component of Section 106 compliance at the INL CRMO, building off preliminary efforts showing the efficacy of the technology in separating geochemical groups within local ceramic assemblages (Freund et al. 2025). The INL CRMO is currently collaborating with the Idaho Museum of Natural History and Shoshone-Bannock Tribes Cultural Resources to produce a database of ceramic geochemical groups of eastern Idaho and INL in particular. The existence of such groups implies the presence of separate paste recipes that likely indicate the use of different clay sources. One of the inferences that can be made using this methodology concerns the recognition of local versus nonlocal ceramic wares, under the assumption that the elemental groups that are most often represented in an assemblage are more likely to be produced from local clays and tempers (Emmitt et al. 2018; Frahm 2018). Comparing and contrasting geochemical groups between and among sites and correlating these patterns to other technological and typological attributes have also been shown to be an effective way of reconstructing ceramic production practices and operational sequences that begin with the procurement of raw materials and end with eventual discard (e.g., Amicone et al. 2020; Michałowski et al. 2020; Ownby 2012; Tanasi et al. 2024). Attempts by the INL CRMO are also being made to source these artifacts to the clay sources or river basins from which they were collected using a comparative database of local clays collected from across the region (Freund, Pink, et al. 2026).

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These efforts align with significant research themes and questions outlined in the PCC, including most notably the theme of "Technology, Adaptive Strategies, and Mobility" and associated questions about ceramic production practices in eastern Idaho (INL CRMO 2026:151–152). Indeed, one of the ways in which the archaeological significance and NRHP eligibility of a precontact property can be assessed is through an understanding of the various mechanisms through which artifacts were produced, used, and subsequently discarded. A critical aspect of this research is thus the identification of strategies to contextualize sites with ceramics and make associated eligibility recommendations, in turn supporting the INL mission and effectively managing cultural resources in compliance with federal laws.

Preservation and Restoration of EBR-I

In 2025, the INL CRMO began consultation with the Idaho SHPO on a preservation plan for Experimental Breeder Reactor I (EBR-I), a nuclear reactor complex and National Historic Landmark that is uniquely important in the history of nuclear energy both nationally and globally. The EBR-I reactor was constructed between 1949 and 1951 and was the first to breed plutonium from uranium, and on December 20, 1951, the reactor produced electricity for the first time, lighting a string of four incandescent light bulbs (Stacy 1999).

One of the key problems identified in the EBR-I preservation plan is the deteriorating condition of bricks throughout the facility. Repairs have been executed on wall sections that were severely water-damaged, using bricks of unknown provenance that are inconsistent with the original appearance of the building. Using XRF, the INL CRMO was able to characterize the geochemical composition of EBR-I bricks as a first step in a longer-term effort to identify the provenance of material used in its construction (Pink and Freund 2026). If the origin of the EBR-I bricks can be determined, it may be possible to identify more appropriate sources of reclaimed brick for use in future restoration efforts.

Case Study 2: NAFB, Nevada

NAFB cultural resources managers are responsible for the management of lands and associated archaeological sites on the Nevada Test and Training Range (NTTR), which covers upwards of 13,000 km^2 of basin and range topography that includes portions of the Mojave and Great Basin Deserts, as well as the Southwestern Nevada Volcanic Field, the geologic source of many of the lithic artifacts found across the region. These sites and resources are significant to Native peoples today, testifying to their existence on these lands since time immemorial (see Stoffle et al. 2001).

In 2005, archaeological research sponsored by NAFB examined what was, at the time, the largest collection of obsidian artifacts (n = 2,015) across southern Nevada and adjacent areas in California and southwestern Utah (Haarklau et al. 2005). The primary goal of this study was to understand the distribution of materials from the Obsidian Butte Volcanic Center located on the NTTR (and unrelated to the Obsidian Butte in California) with the explicit aim of developing and operationalizing research questions to study and evaluate cultural sites. The research questions driving the study included the following:

- What obsidian sources are present on government-managed lands, and how are those sources defined geologically, spatially, and geochemically?
- How does the distribution of obsidian, both geologically and archaeologically, align with Indigenous food procurement strategies?
- How does obsidian exploitation change through time?
- How does obsidian-sourcing reinforce the cultural value of prominent landscape areas, specifically those comprising the Obsidian Butte Volcanic Center?

Unfortunately, Haarklau and colleagues' (2005) research, while influential, has only partially contributed to follow-up work managing cultural sites overseen by the US Air Force. This is largely because no major research or undertakings requiring data recovery have occurred since the 2005 study and because NAFB has a no-collection policy, except under special conditions. This has effectively meant that no new geochemical studies could be done unless artifact collection was warranted as part of a Historic Properties

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Treatment Plan (HPTP) for mitigation or some other extenuating circumstances, under the assumption that geochemical work could only be done through collection and curation (this was certainly the case in 2005). Moreover, the current ICRMP for NAFB does not have obsidian-sourcing as a research constituent. Today, portable XRF enables in-field geochemical analysis, which has the capacity to test hypotheses developed by Haarklau and colleagues (2005) and in turn be integrated into Section 106 site characterization efforts and NRHP eligibility recommendations.

Most precontact archaeological sites on the NTTR are surficial lithic scatters, similar to much of southern Idaho and the Great Basin, but to date, patterns of obsidian distribution and use have been based on projectile point analysis without a consideration of debitage or other tools. Thus, source exploitation is only seen through a narrow lens that overlooks the entire *chaîne opératoire* of regional lithic economies (Freund et al. 2022). Sourcing analysis of all classes of lithic artifact are warranted, which can be facilitated by in-field analysis with portable XRF. For example, some ecozones in the NTTR are high-elevation pinyon-juniper forests with no local toolstone resources, and such areas represent gathering places where populations met and interacted for extended periods. In-field XRF analysis of a representative sample of artifacts—situated in social gathering places in particular—can address questions pertaining to site function, population interactions, and material exchange at a level of detail beyond what is possible from analyses of discarded tools alone. If, for example, pinyon-juniper groves are social spaces and centers of gravity, we would expect the presence of a wider diversity of obsidian sources compared with other temporary camps.

Additional metrics can also be used to assess the relative occupation span of a site, including the quantity or density of artifacts, ratios of tools to debitage, reduction intensity, and ratios of local to nonlocal materials (Barton and Riel-Salvatore 2014; Grove et al. 2023; Pink 2025b; Surovell 2009). Here, provenance data become especially useful for helping determine ratios of local to nonlocal tools and materials. Since occupation span is inversely related to the frequency of residential moves (Grove 2018; Surovell 2009), information on site-level source use may provide insight into the rate of residential mobility at discrete points on the landscape, contributing to an understanding of how use of those locales fits into broader patterns of seasonal mobility (Pink 2025b).

As with the Idaho examples, XRF analysis aligns well with existing research themes outlined in the NAFB ICRMP (Nellis Air Force Base [Nellis AFB] 2025), such as "Chronology," "Settlement/Subsistence," and "Tool Stone Procurement, Use, Trade, and Transport." Data requirements for addressing research questions from such themes include temporally diagnostic artifacts or materials (e.g., known projectile point types), assemblages able to be classified as one of several site types (lithic scatters, habitation, temporary camps, etc.), cultural features that may demonstrate short- to long-term (ceremonial) habitation or site use (e.g., rock circles, petroglyphs, pinyon groves), and artifacts that may inform mobility or exchange (e.g., obsidian that can be sourced). Currently, the NAFB ICRMP (Nellis AFB 2025) considers sites with more than 100 pieces of obsidian as eligible for listing in the NRHP. Recurrent and consistent in-field XRF analysis can add nuance to such arbitrary considerations and expand the range of relevant research questions that can be addressed and integrated into NRHP eligibility recommendations.

Operationalizing in-field XRF in the manner suggested above can improve managerial efficiencies for federal cultural resources programs. In the case of NAFB, previous cultural resources program managers have classified large numbers of sites as "unevaluated" for NRHP eligibility, presumably because they felt additional studies or more data were necessary to appropriately characterize or evaluate the sites. Leaving sites unevaluated creates additional work for future program managers, particularly when turnover or gaps in the administrative record lead to unfinished business falling through the cracks. Unevaluated sites must be treated as NRHP eligible for the purposes of the Section 106 process, so it behooves program managers to make a determination whenever feasible.

Discussion and Conclusions

Through two case studies, this study demonstrates how XRF can be effectively integrated into Section 106 processes through the analysis of commonly encountered archaeological materials such as lithics, ceramics, and brick. It is further shown how such analyses can make meaningful contributions to

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site characterization efforts, NRHP eligibility recommendations, and preservation. Two federal programs are discussed, and while they are similar, in that surface manifestations of lithic debris are the most commonly encountered precontact resources, they nonetheless highlight how the integration of XRF technology can occur within programs with different funding capacity to justify the purchase of instrumentation, personnel, and organizational goals. Moreover, these case studies occur within archaeological contexts with different histories of academic study and foundational documentation within which to situate XRF results.

The need for context documents in justifying XRF analyses is stressed because XRF results are only as powerful as the interpretive framework within which they are anchored. For compliance archaeology, context documents provide the foundation for agency decisions in the identification, evaluation, and treatment of historic properties and should be created or revised with XRF integration in mind. For CRM professionals, beyond the inherent availability of funds, the purchase of instrumentation also requires support from management, which can be demonstrated through the creation of such documents. At its core, the integration of XRF analysis with robust contextualization leads to reduced time and costs for consultation and shared understandings between an agency, SHPO, Tribes, and stakeholders.

XRF analysis can also help to minimize the ambiguity that may lead to sites with an "unevaluated" NRHP status. Furthermore, consistent implementation of XRF analysis can reveal patterns or relationships between chronology, site type, and source diversity that can feed back into the research themes and data requirements used to evaluate sites that are codified in a historic context, CRMP, or ICRMP. In this way, arbitrary thresholds—such as considering sites with 100 or more obsidian artifacts to be eligible—can be replaced with well-contextualized research questions and evaluation criteria.

Many federal agencies, including NAFB, do not own an XRF instrument or possess a database of geological obsidian. This issue can be overcome by renting an instrument as needed, or by requiring contractors to employ XRF for site characterization or data recovery. This raises important methodological questions about the prospect of sourcing obsidian in the absence of a physical database of source material or when multiple instruments and associated analytical protocols are being used. Indeed, it is accepted practice and generally best to compare artifact data directly with source materials analyzed by the same instrumentation due to inherent inconsistencies between individual XRF instruments (Glascock et al. 1998). However, in certain contexts it may be possible, depending on the similarities in elemental composition of the various obsidian sources of a region. If differences in elemental readings across instruments are systematic, they can be corrected for by using regression models, machine-learning workflows, or similar statistical techniques (Drake et al. 2022; Hnila et al. 2025). Further study is warranted to more clearly define the contexts where this may be possible.

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