LAKHÕMI JOURNAL
SCIENTIFIC JOURNAL OF CULTURE

The Chemistry of Devotion: Materials, Techniques, and Symbolism in Ethiopian Sacred Metalwork and Manuscript Illumination

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Abstract:

Ethiopian sacred arts represent one of the world's oldest continuous traditions of material and spiritual transformation, yet the chemical knowledge embedded in these practices remains largely unexplored in the historiography of science and art history. Purpose: This study examines Ethiopian sacred metalwork and manuscript illumination as a form of applied alchemy, investigating the practical chemistry, techniques, and theological symbolism underlying these traditions. Drawing on interdisciplinary approaches combining archaeometric analysis (X-ray fluorescence spectroscopy, Raman spectroscopy, Fourier Transform Infrared Spectroscopy, and Pyrolysis-Gas Chromatography–Mass Spectrometry), art historical examination, ethnographic documentation, and textual analysis, this study synthesizes existing research and presents new interpretations of Ethiopian sacred material culture. Ethiopian artisans possessed sophisticated indigenous chemical knowledge encompassing metallurgy (smelting, lost-wax casting, alloying, gilding), parchment-making, ink preparation (carbon-based and iron-gall inks), and pigment production (mineral, plant-based, and imported pigments). This practical chemistry was deeply intertwined with theological symbolism: gold signified divine light, red represented the blood of Christ, and the processes of transformation were understood as acts of purification and devotion. The Ethiopian tradition, continuous since late Antiquity, serves as a vital source for understanding vanished historical practices. Ethiopian sacred arts constitute a distinctive tradition of applied alchemy that challenges Eurocentric narratives of chemical knowledge, demonstrating that sophisticated material practices flourished in non-European contexts. Future research should prioritize systematic chemical analysis of wider manuscript and metal object corpora, ethnographic studies of living craftspeople, comparative studies with other African and Eastern Christian traditions, and digital humanities approaches to preserve and analyze this endangered heritage.

Keywords:
Ethiopian Orthodox Church; sacred metalwork; manuscript illumination; indigenous chemistry; material culture

I. Introduction

1.1 Defining the Scope

Ethiopia is home to one of the world's oldest continuous Christian civilizations, with a distinctive artistic heritage that has served as a material expression of Orthodox Christian faith since the conversion of the Aksumite Empire to Christianity around 330 CE. The sacred material culture of the Ethiopian Orthodox Tewahedo Church encompasses a remarkable range of objects: cast metal processional crosses, chalices, censers, and crowns; illuminated manuscripts on parchment; icons painted on wood; and vibrant mural cycles adorning church interiors. The cross (mäsqäl) is central to devotion and a preeminent cultural icon in the Ethiopian Orthodox Tewahedo Church, having become the object of intense devotion soon after the Aksumite Empire's conversion (Metropolitan Museum of Art, n.d.). Processional crosses are carried on

DOI: *https://doi.org/10.5281/zenodo.21330818*

long poles in religious processions, serving as emblems of the Church's ongoing authority (Brooklyn Museum, n.d.). The majority of Ethiopian crosses were cast in brass using the lost-wax casting technique; because this method allows for only one unique object to be created from each mold, it may have contributed to the extraordinary diversity of Ethiopian cross forms (Metropolitan Museum of Art, n.d.).

Ethiopian sacred metalwork is distinguished by its remarkable variety of form and material composition. Technical studies have revealed that bronze was the alloy used to make the earliest crosses (twelfth–fourteenth centuries), while later crosses (post-fifteenth century) were made of brass and gunmetal, with a transitional period during the fourteenth–fifteenth centuries showing greater variety including copper, bronze, and brass (Harrison, 2022). Some crosses also feature intentionally applied black material in engraved designs and punchwork, which recent multi-analytical studies have begun to characterize (Bailey et al., 2025). The Walters Art Museum includes within its collection twelve Ethiopian copper-alloy crosses dating from between the twelfth and twentieth centuries, eight of which feature what appears to be intentionally applied black material (Bailey et al., 2025).

1.2 Theoretical Framework: Alchemy as Practical Chemistry

The term "alchemy" has traditionally been associated with the Greco-Egyptian tradition of seeking to transmute base metals into gold, a pursuit that, in its Western formulation, emerged from the fusion of Egyptian technical craftsmanship and Greek philosophical speculation in Hellenistic Alexandria. However, recent scholarship has begun to expand the concept of alchemy beyond this narrow definition to encompass a broader range of indigenous chemical knowledge systems. As Loubser and Le Roux (2021) have argued, the application of scientific analysis to African art objects can reveal "a whole new layer of information" that enriches our understanding of their spiritual significance. In their investigation of a century-old Ethiopian prayer scroll and a contemporary South African sculpture, they demonstrated how X-ray fluorescence spectroscopy (XRF) and technical photography can reveal the composition of materials used by artists, adding to the aesthetic and spiritual impact of the work (Loubser & Le Roux, 2021). They suggest that this "alchemy", the materiality of spiritual expression in artistic creation can reveal aspects of which even the artists themselves may have been unaware (Loubser & Le Roux, 2021).

This study adopts this broader theoretical framing, conceptualizing Ethiopian sacred making as a form of "applied alchemy" in which practitioners; blacksmiths, goldsmiths, scribes, and painters applied sophisticated empirical knowledge of materials and their transformations to create objects that participated in the divine. The metalworker who smelted ore and cast it into a processional cross; the scribe who prepared parchment from animal skins and mixed carbon black with plant gums to produce ink; the painter who ground minerals and plants into vibrant pigments—each engaged in a form of practical chemistry that was simultaneously technical, ritual, and theological. This framing aligns with scholarship that has explored the "alchemy" of African artistic creation as a material expression of spiritual meaning. The Ethiopian magic scrolls, traditional parchment artifacts used by Christians of Ethiopia as protection against disease and demonic possessions, exemplify how the materiality of sacred objects—their inks, pigments, and supports was integral to their spiritual function (Vadrucci et al., 2023).

1.3 The Argument

This study advances three interconnected arguments. First, the preparation and use of materials in Ethiopian sacred metalwork and manuscript arts represent a sophisticated

indigenous chemical knowledge system that was transmitted across generations through apprenticeship, oral tradition, and practical demonstration. This knowledge encompassed an empirical understanding of the properties of metals, alloys, pigments, binders, and other materials, as well as the techniques required to transform them into durable, aesthetically powerful objects. The Ethiopian tradition of manuscript production is "continuous since at least late Antiquity," serving as "an important source for analogies to those who wish to better understands vanished historical practices" (Ethiopian Manuscript Culture, 2016). The survival of these ancient techniques into the modern period is attested by ethnographic documentation: scribes in Andabet, south of Debre Tabor, continue to make their own black ink from carbon, typically soot from cooking pots mixed with starchy liquid from infused cereal grains, stirred daily for at least three months until a skin forms, which is then dried into blocks and reconstituted as needed (Mellors, 2009). Pens are made from reeds and parchment from goatskins (Mellors, 2009).

Technical analysts have begun to characterize the material composition of Ethiopian sacred objects. Harrison's (2022) study of Ethiopian copper alloy processional crosses through X-ray fluorescence analysis (XRF) documented fabrication methods, repairs, and patterns in alloy type related to cross style and chronology. The study found that bronze was the alloy used to make the earliest (twelfth–fourteenth century) crosses, while later crosses (post-fifteenth century) were made of brass and gunmetal (Harrison, 2022). Bailey, Shulman, and Elliott (2025) employed Fourier Transform Infrared Spectroscopy (FTIR) and Pyrolysis-Gas Chromatography–Mass Spectrometry (Py-GC-MS) to characterize black materials applied to historic Ethiopian processional crosses. Vadrucci et al. (2023) applied a combined approach of Infrared Reflectography (IRR), Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy, and Ion Beam Analysis (IBA) to characterize inks and pigments on Ethiopian magic scrolls. Wion (2004) analyzed pigments from two masterpieces of seventeenth-century Ethiopian art—an illuminated manuscript of the Miracles of Mary and a mural painting from Abba Antonios church in Gondar—using Raman micro-spectroscopy, demonstrating that the pigments used were those favored among aristocratic society of the seventeenth century and that most were part of the international luxury goods trade of the time. These scientific studies, while still limited in number, demonstrate the potential for archaeometric approaches to illuminate the chemical knowledge embedded in Ethiopian sacred arts.

II. Review of Literature

2.1 The Metallurgical Tradition – From Ore to Sacred Object

a. Sources of Metal: Geological Resources in the Ethiopian Highlands

The Ethiopian highlands are endowed with a diverse array of metallic mineral resources that have been exploited since antiquity. Gold, iron, copper, and silver, the principal metals of Ethiopian sacred material culture were all available within the territory of the Aksumite and subsequent Ethiopian empires, though access to these resources varied across time and political circumstances.

Gold has been mined in Ethiopia since ancient times and remains the country's most significant metallic mineral export (Mining in Ethiopia, 2008). Alluvial gold was discovered and worked in various regions, with the Adola area in Sidamo being a notable site of historical extraction (Ethiopia - Mining, n.d.). The Aksumite kingdom, which controlled much of the northern highlands, was a major consumer of metal objects for trade, warfare, agriculture, stone carving, and ornamentation (Robion-Brunner, 2024). Herodotus, writing in the fifth century

BCE, noted that "where the south declines towards the setting sun lies the country called Ethiopia, the last inhabited land in that direction. There gold is obtained in great plenty" (Markowitz, 2021). The supply of gold was closely controlled by the Aksumite state, enabling the kingdom to ensure the usage of its coinage and to participate in international trade networks extending to Egypt, Rome, Persia, and India (Markowitz, 2021).

Iron ore was widely available in the Ethiopian highlands, and its exploitation was central to the technological and military capabilities of Ethiopian states. Archaeological and archaeometallurgical investigations at Aksum have revealed that iron smelting was conducted using locally available lateritic iron ores containing at least 80 wt% FeO (Severin et al., 2011). The indigenous knowledge of iron smelting was present in various parts of the country, with ethnoarchaeological research attesting to the diversity of technological and socio-cultural aspects of iron production among different Ethiopian societies (Indigenous Iron smelting in Ethiopia, n.d.). In the 19th century, local people of Wallagga were engaged in the extraction of gold as well as iron, bringing the items to local markets in western Ethiopia (A History of Mining in Wallagga, n.d.).

b. The Chemistry of Smelting: Thermodynamics, Fluxes, and Ritual

The transformation of raw ore into workable metal represents one of the most significant technological achievements of ancient Ethiopian civilization. The chemistry of smelting involved the application of heat in carefully constructed furnaces to reduce metal oxides to their elemental forms through a process of carbothermic reduction.

Iron Smelting: The Bloomery Process

Archaeometallurgical analysis of remains from 3rd–4th century AD Aksum has provided detailed insight into Ethiopian iron smelting practices. Chemical and mineralogical analyses of archaeometallurgical remains have excluded a relationship to copper smelting; instead, all samples are consistent with a highly efficient iron smelting operation using the bloomery process and slag tapping furnaces (Severin et al., 2011). The bloomery process, which was widely practiced across sub-Saharan Africa, involves heating iron ore with charcoal in a furnace; the carbon monoxide produced by the combustion of charcoal reduces the iron oxides to metallic iron, which forms a spongy mass (the bloom) at the bottom of the furnace.

A lateritic iron ore containing at least 80 wt% FeO was smelted, resulting in an estimated one unit by weight of iron metal produced for every unit by weight of slag left behind, with little erosion of furnace wall material (Severin et al., 2011). This represents a remarkably efficient operation by pre-industrial standards. The zoning of spinels, with chromium- and aluminum-rich inner parts and mixed hercynitic-ulvitic outer rims, reflects the evolution of the melt phase under strongly reducing conditions (Severin et al., 2011). The bloomery furnace operated at temperatures sufficient to reduce the iron oxides but not to melt the iron itself, which remained in a solid, spongy state requiring subsequent forging to consolidate and shape it.

Ethnoarchaeological research in southwestern Ethiopia has documented iron smelting traditions that persisted until the mid-twentieth century. In Wollega, western Ethiopia, iron smelting was conducted in pit furnaces, a type not ethnographically observed clearly in other parts of Africa (Iron Smelting in Wollega, n.d.). The furnace was non slag-tapping, eliminating oxidation of the bloom and temperature drop in the furnace due to slag removal (Historical Metallurgy, n.d.). The bloom was centrally situated in the furnace and was extracted through the top, limiting damage to the furnace to cracking of the clay during the smelt (Historical Metallurgy, n.d.). In southwestern Ethiopia, bloomery iron was produced from limonite and

magnetite ores, with ground ore melted with charcoal in clay furnaces rising about one meter above the ground, using a system of thirty-six blowpipes to provide the necessary air (Iron smelting in south-west Ethiopia, n.d.).

c. The Blacksmith's Art: Social Status, Techniques, and Craftsmanship

The social and spiritual status of metalworkers in Ethiopian society was complex and ambivalent. On one hand, blacksmiths, goldsmiths, and silversmiths were essential to the functioning of both secular and sacred institutions, producing the weapons that secured political power and the sacred objects that mediated divine presence. On the other hand, they were often marginalized and subjected to social stigma.

Social Status and Marginalization

For centuries, several ethnic groups of Ethiopia have considered physical labor and crafts, including blacksmithing, weaving, dyeing, and woodworking, as "unworthy" occupations compared to agriculture (Social Differentiation, 2024). The institutions of discriminated groups, which were established in antiquity, have shown their resilience over several centuries (Social Differentiation, 2024). In Ethiopia, there was a very unique phenomenon where social hierarchy was institutionalized through "castes" of artisans, with blacksmiths, potters, tanners, and weavers occupying the lowest rungs of the social ladder (Social Differentiation, 2024).

Similar to marginalized occupational specialists in many societies across Africa, eastern Tigray's potters and smiths are marginalized, avoided, and demeaned in contexts where food, drink, or sex is shared (Lyons, 2014). Potters and blacksmiths transgress normative gender expectations by using technological skills and space differently (Lyons, 2014). The embodiment and performance of their respective crafts are perceived to transform them into different ontological categories (Lyons, 2014). In Ethiopia, the trade of silversmith was practiced by the Jews of Ethiopia, otherwise known as the Falasha Clan, and the activity was considered to be inferior to others, as reliant on manual skills (Silversmith, 2013).

Yet despite this marginalization, the practical importance of metalworkers was undeniable. The power of the smiths was closely tied to their technology; as these areas were brought under national rule, the power of the smiths suddenly became irrelevant as the new rulers did not rely on their technology (Incorporation into the new Ethiopian state, n.d.). The role of silversmiths was often linked to traditional ruling families, demarcating social differences in a still largely non-literate society (Murahashi, 2007).

d. Sacred Objects in Metal

Ethiopian metalworkers produced a remarkable array of sacred objects for the Orthodox Church, each with specific liturgical functions and theological meanings.

Processional Crosses (Qäqwami Mäsqäl)

The processional cross is among the most iconic forms of Ethiopian sacred art. Carried on long poles in religious processions, these crosses serve as emblems of the Ethiopian Orthodox Church's ongoing authority (Brooklyn Museum, n.d.). The majority of Ethiopian crosses were cast in brass using the lost-wax casting technique (Metropolitan Museum of Art, n.d.). Images of Christ are rare in Ethiopian crosses, reflecting Ethiopian Orthodoxy's dual belief in the cross as a sign of the Crucifixion and the Tree of Paradise (Metropolitan Museum of Art, n.d.). The cross form is intricate and abstract in design, with geometric and often lace-like patterning ornamenting the central cross (Carlos Museum, n.d.). Large brass crosses are mounted on wooden shafts, accented by colorful ribbons and processed during the service (Carlos Museum,

n.d.). Hand crosses, which are used by priests, are either hand-held or suspended from a cord around the neck; they are kissed by the faithful to receive a blessing (Brooklyn Museum, n.d.).

Technical study of Ethiopian copper alloy processional crosses has revealed patterns in alloy type related to cross style and chronology. Bronze was identified as the alloy used to make the earliest (twelfth–fourteenth century) crosses, while later crosses (post-fifteenth century) were found to be made of brass and gunmetal (Harrison, 2022). Crosses dating to a transitional period during the fourteenth–fifteenth century were made of a greater variety of materials including copper, bronze, and brass (Harrison, 2022). While the difference in alloy types may be related to changing preferences or access to certain metals, the mass removal of religious art in the sixteenth century could have also impacted the types of crosses that remain (Harrison, 2022).

Some crosses feature intentionally applied black material in engraved designs and punchwork. A multi-analytical study of black materials on historic Ethiopian Orthodox copper-alloy crosses has characterized these materials, noting their visual similarity to black materials on contemporaneous inlaid Islamic metalwork (Bailey et al., 2025). The square at the base of the shaft of many hand crosses symbolizes the Ark of the Covenant, which is believed to have come to Ethiopia from Jerusalem, and the tomb of Adam, which is believed to have been at the foot of Christ's cross (Smithsonian Institution, n.d.).

Chalices and Patens

The chalice and paten are the most important liturgical vessels, used at the altar by the priest for the consecration of the Eucharistic bread and wine during the celebration of the mass (Cleveland Museum of Art, 2024). In Ethiopia, the communion chalice is used to hold communion wine, believed by the faithful to be the blood of Christ (British Museum, n.d.). The wine is made by soaking dried grapes in water and is unfermented (British Museum, n.d.). A sublime example from the Cleveland Museum of Art is decorated with filigree enamel consisting of twisted gold wire forming a floral design, which in turn is filled with colorful glass pastes (Cleveland Museum of Art, 2024). The stand of the chalice as a *kibootos* (Ark) refers to the Ark of the Covenant, while its indication as a *thronos* alludes to the heavenly Throne in texts such as Isaiah 6, Ezekiel 1 and 10, and Revelation 4 (The Stand of the Chalice, n.d.).

e. Symbolism of Metals

The choice of metal for a sacred object was not arbitrary but was governed by a rich system of theological symbolism, drawing on biblical typology and local interpretive traditions.

Gold: Divinity, Incorruptibility, and Kingship

Gold is the supreme metal in Ethiopian sacred art, signifying divinity, incorruptibility, kingship, and the uncreated light of God. The use of gold in sacred objects reflects the theological conviction that the divine realm is characterized by radiance, permanence, and purity. Gold was associated with the heavenly realm and with the kingship of Christ. In Ethiopian Orthodox theology, the gold used in processional crosses, crowns, and liturgical vessels participates in the divine light, making the object a point of contact between heaven and earth. The use of gold in Aksumite coinage and royal insignia similarly signified the divine authority of the king. As noted in the trilingual stone inscription of King Ezana, to celebrate his victory over the Bāqa people, Ezana erected statues of gold, of silver, and of bronze (Robion-Brunner, 2024).

Silver: Purity, Redemption, and the Moon

Silver represents purity, redemption, and the moon in Ethiopian symbolic systems. Silver was associated with the redemption accomplished by Christ and with the purity required of those who approach the divine. Silver objects, including hand crosses and jewellery, were valued for their purity and their association with the moon's reflected light. The use of silver in Aksumite coinage and in later Ethiopian silverwork reflects its status as a precious metal of high symbolic value. In the Bible, silver is associated with redemption and atonement (Symbolism of Materials and Colors, n.d.).

Iron: Strength, Warfare, and Spiritual Battle

Iron symbolizes strength, power, and the capacity for warfare and spiritual battle (Symbolism of Materials and Colors, n.d.). In Ethiopian Orthodox tradition, iron crosses and iron objects are associated with the overcoming of evil and the spiritual warfare in which Christians are engaged. Iron was the metal of the warrior and of the smith who armed the armies of the Ethiopian kingdoms. The use of iron clamps in the construction of Aksumite monuments and the presence of iron weapons in tombs attest to the central role of iron in Ethiopian political and military power. Yet iron also had ambivalent associations, as the smith who worked iron was often marginalized and feared for his dangerous power.

Bronze and Brass: Durability and the Fusion of Qualities

Bronze (copper-tin) and brass (copper-zinc) were the primary materials for processional crosses and many other sacred objects. The durability of these alloys made them suitable for objects that would be handled, carried in processions, and displayed in churches over many centuries. Bronze symbolizes judgment and strength (Symbolism of Materials and Colors, n.d.), while brass, with its golden appearance, could evoke gold while being more accessible and durable. The shift from bronze to brass and gunmetal in Ethiopian crosses after the fifteenth century (Harrison, 2022) may reflect changing access to metals, evolving aesthetic preferences, or both.

f. Case Studies

Case Study 1: Lalibela Processional Crosses

Figure 1 illustrates the historical, technological, and artistic significance of the Lalibela processional crosses, which represent some of the earliest surviving examples of Ethiopian sacred metalwork from the Zagwe Dynasty (c. 1137–1270). The figure highlights the remarkable application of the lost-wax (cire perdue) casting technique, enabling artisans to produce highly intricate openwork designs and complex geometric motifs that symbolize Christian theology and Ethiopian cultural identity (Harrison, 2022). Technical analyses indicate that the earliest crosses were cast primarily from bronze, reflecting advanced metallurgical knowledge and craftsmanship. Their balanced proportions, rotational symmetry, interlaced lattice patterns, and sophisticated openwork demonstrate exceptional mathematical precision and engineering principles embedded within indigenous artistic traditions. Beyond their liturgical function, these crosses embody the integration of technology, geometry, religion, and cultural heritage, illustrating the remarkable scientific and artistic achievements of medieval Ethiopian civilization (Harrison, 2022; Zach, 2018).

Figure 1. Lalibela processional crosses illustrating advanced lost-wax casting, geometric craftsmanship, bronze metallurgy, and the integration of Ethiopian sacred art and engineering.

Case Study 2: Aksumite Coinage

Figure 2 illustrates the technological sophistication and economic significance of Aksumite coinage, the earliest indigenous currency system produced in sub-Saharan Africa during the third century AD. The figure highlights the standardized minting of gold, silver, and bronze coins, with the gold unit weighing approximately 2.7 g, equivalent to half of the contemporary Roman *aureus*, facilitating regional and international trade (Markowitz, 2021). The obverse features the royal portrait flanked by ears of grain, symbolizing prosperity, while the crescent and solar disc represent the celestial deities of pre-Christian Aksumite religion. Greek inscriptions on the obverse and Ge'ez inscriptions on the reverse demonstrate the kingdom's commercial integration with the Mediterranean world while preserving indigenous linguistic identity. These design elements reflect advanced metallurgy, mathematical standardization, iconographic precision, and sophisticated state administration, illustrating the scientific and cultural achievements of the Aksumite civilization (Markowitz, 2021).

Figure 2. Aksumite coinage illustrating standardized metallurgy, mathematical precision, royal symbolism, bilingual inscriptions, and the economic sophistication of ancient Ethiopian civilization.

One of the most curious aspects of Aksumite coinage is the use of gilding on some of the silver and bronze coins. The amount of gold used would not be enough to significantly change the value of the coin, and the reason for this labor-intensive process remains somewhat a mystery (Aksumite coinage, n.d.). Some Aksumite silver coins had gold "inlays" on or around the royal portrait, a labor-intensive enhancement that made for more impressive coins of richer perceived value (Markowitz, 2021). Later, even low-value coppers were embellished with gold leaf (Markowitz, 2021).

Archaeological excavations in Aksum have recovered hundreds of bronze and silver coins dated from the 3rd to the 7th century AD, minted during the reigns of different Aksumite kings (Robion-Brunner, 2024). The excavations of Dungur palace yielded numerous coins and numerous bronze and iron objects including scissors, pendants, rings, bracelets, chisels, metal clamps, nails, hooks, and other objects (Robion-Brunner, 2024). The British Institute in Eastern Africa excavations yielded silver and copper beads and 178 silver and bronze Aksumite coins (Robion-Brunner, 2024). A large quantity of gold, iron, silver, and copper/golden silver objects were found in tombs in the Gudit stelae field, including personal ornaments, agricultural and domestic equipment, weapons, building objects, and animal and human figurines (Robion-Brunner, 2024).

Case Study 3: Solomonic Crowns and Royal Insignia

Figure 3 illustrates the technological sophistication and symbolic significance of Solomonic crowns and royal insignia as enduring representations of Ethiopian kingship, religious authority, and statehood during the Solomonic period (c. 1270–1974). The figure highlights the elaborate gold crowns, including Emperor Menelik II's Triple Crown, which exemplifies exceptional craftsmanship through filigree, gemstone settings, repoussé metalwork, and geometric ornamentation (Commemorative Medal, n.d.). The royal seal, featuring the imperial crown, two angels protecting the *Tabot* (Ark of the Covenant), and the Lion of Judah, symbolizes the divine legitimacy of the Solomonic dynasty and its claimed descent from King Solomon and the Queen of Sheba (Ethiopia – Headdress, n.d.). Collectively, these royal regalia demonstrate advanced Ethiopian metallurgy, artistic innovation, religious symbolism, and political ideology, reflecting the integration of sacred authority with imperial governance throughout Ethiopian history.

Figure 3. Solomonic crowns and royal insignia illustrating Ethiopian imperial authority, sacred symbolism, advanced goldsmithing, religious heritage, and enduring artistic excellence.

Case Study 4: Technical Examination of Alloys and Decorative Methods

Figure 4 presents the technological evolution of Ethiopian copper alloy processional crosses over eight centuries, emphasizing the application of advanced non-destructive analytical techniques for cultural heritage research. The figure illustrates the use of X-ray fluorescence (XRF)**,** X-radiography**, and** scanning micro-XRF to characterize alloy composition, fabrication methods, and historical repairs without damaging the artifacts (Harrison, 2022). XRF analysis of 20 crosses revealed a clear chronological transition in metallurgical practices, with early (twelfth–fourteenth century) crosses manufactured primarily from bronze, transitional (fourteenth–fifteenth century) examples exhibiting copper, bronze, and brass alloys, and later (post-fifteenth century) crosses predominantly composed of brass and gunmetal (Harrison, 2022). Scanning micro-XRF successfully identified solder joints and cast-on repairs, providing unprecedented insight into manufacturing technologies, conservation history, and the remarkable metallurgical expertise of Ethiopian artisans across successive historical periods.

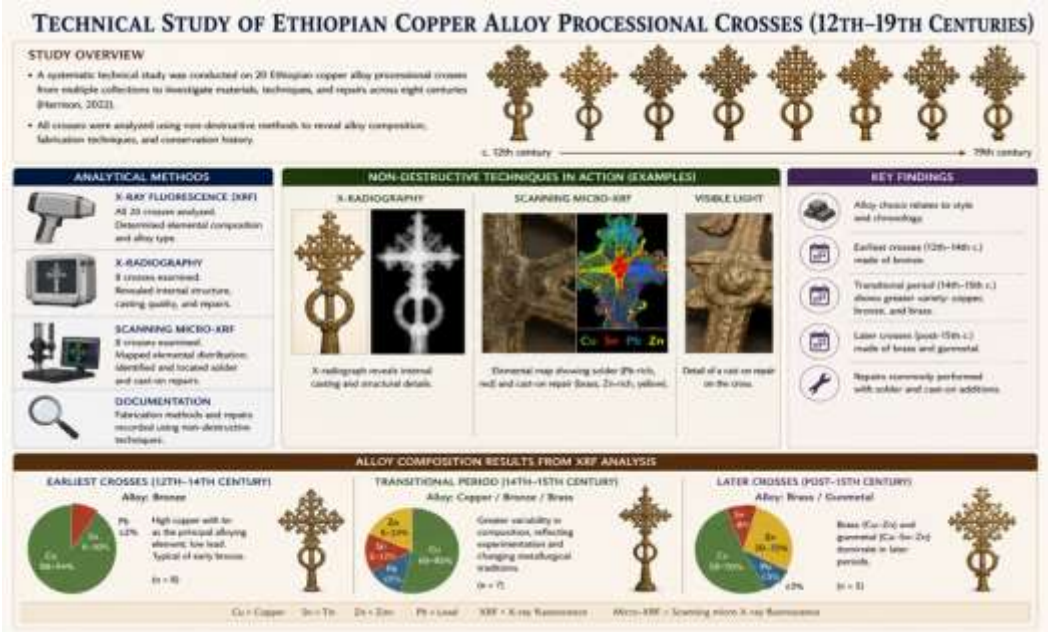

Figure 4. Non-destructive analysis of Ethiopian processional crosses revealing chronological alloy evolution, fabrication techniques, repair history, and advanced indigenous metallurgical innovation.

The multi-analytical study of black materials applied to historic Ethiopian processional crosses employed Fourier Transform Infrared Spectroscopy (FTIR) and Pyrolysis-Gas Chromatography–Mass Spectrometry (Py-GC-MS) to characterize the composition of these materials (Bailey et al., 2025). The visual similarity of black materials on Ethiopian Orthodox crosses to black materials on contemporaneous inlaid Islamic metalwork has been noted, suggesting possible technical connections or shared traditions (Bailey et al., 2025).

III. Research Methods

3.1 The Manuscript Tradition – Preparing the Surface for the Word

a. The Significance of the Manuscript: The Manuscript as Sacred Object

The Ethiopian tradition of manuscript production represents one of the longest-lived continuous traditions of book production in the Christian world, yet it remains one of the most understudied (Winslow, 2016). The tradition of creating manuscripts on parchment in Ethiopia is very long, probably longer than the presence of Christianity in this area (Liszewska et al., n.d.). Parchment, called *biranna* in Ethiopia, has been widely used since antiquity and continues to be

used today; the technical aspects of this process have not changed significantly through the centuries and remain "quite simplified and in many ways very similar to the processes used in the beginning of our era" (Liszewska et al., n.d.). The Ethiopian manuscript tradition is continuous since at least late Antiquity and serves as "an important source for analogies to those who wish to better understand vanished historical practices" (Winslow, 2016, p. 25).

In Ethiopian Orthodox Christianity, the manuscript is far more than a textual repository; it is a sacred object, the material container of divine revelation. The scribe occupies a position of profound spiritual significance, understood as a figure of devotion and learning whose work is an act of worship. As one Ethiopian priest explained, replicating manuscripts "needs patience and focus. It begins with a prayer in the morning, at lunchtime, and ends with prayer" (VOA Africa, 2023). The scribe's labor is understood as a form of devotion that makes the practitioner "worthy in the eyes of God" (VOA Africa, 2023) (Figure 5).

Figure 5. Ethiopian Orthodox manuscript tradition illustrating sacred scribal practices, devotional knowledge transmission, manuscript production, and the preservation of religious heritage through craftsmanship

The manuscript is also understood as a durable object intended to endure across centuries. As one scribe observed, "We copy from paper to parchment to preserve (the writings) as the paper book can be easily damaged, while this one will last a long time if we protect it from water and fire" (VOA Africa, 2023). Another scribe expressed the hope that "in 1,000 years, or more, people will find the books I wrote" (France24, 2023). This aspiration for longevity reflects the theological significance of the manuscript as a vessel for sacred text intended to transmit divine revelation across generations. The overwhelming majority of Ethiopic manuscripts are codices made of parchment, usually bound between two wooden boards, which are covered with leather (Beta maṣāḥəft, 2018).

b. The Chemistry of Parchment-Making

The preparation of parchment is a labor-intensive process that transforms raw animal skins into a durable, smooth writing surface through a combination of chemical and mechanical operations (Winslow, 2016).

Selection of Skin

The primary material for Ethiopian parchment is goatskin, though sheepskins are also used. The Hamere Berhan Institute in Addis Ababa, which has produced numerous manuscripts

since its founding, uses goat skins donated by locals (VOA Africa, 2023). Goatskin is preferred for its durability, flexibility, and the quality of the writing surface it provides (Liszewska et al., n.d.). The selection of skins requires careful judgment, as the quality of the final parchment depends significantly on the condition of the raw material.

Soaking and Liming: The Chemical Process

The first stage of parchment production involves immersing the skins in water for three to four days (VOA Africa, 2023). This soaking serves to rehydrate the skin, loosen the hair, and begin the process of removing fats and other soluble components. The chemistry of this stage involves the hydrolysis of proteins and the swelling of collagen fibers, preparing the skin for the subsequent chemical treatment. Following the initial soaking, the skins are treated with lime (calcium hydroxide, $Ca(OH)_2$) in a process known as liming. The lime solution is alkaline and serves multiple chemical functions: it dissolves hair and fats, saponifies lipids, and causes the collagen fibers to swell, making them more amenable to subsequent mechanical processing (History of the Book, 2022). The vat is stirred two or three times a day during the liming bath to ensure the deep and uniform penetration of the solution (Sewasew, 2021). After liming, the skins are thoroughly washed to remove the lime and the dissolved hair and fat residues.

c. Regional Variations: Differences in Parchment Quality and Preparation Techniques

The Ethiopian manuscript tradition exhibits regional variations in parchment quality and preparation techniques. Fäqadä Sellasé Täfära's comprehensive study, based on a "very vast corpus of manuscripts," takes into account both "synchronicity and regionalism" (Wion, 2010, p. 1). The study deals with cultural and social aspects as the education of scribes, their daily work, and provides some short biographies of famous scribes (Täfära, 2010).

Field research conducted with scribes and manuscript craftsmen in the Ethiopian highlands between 2007 and 2011 has documented the practices of parchmenters in the Ethiopian tradition (Winslow, 2016). This research has revealed variations in tools, techniques, and materials across different regions. Monasteries and scriptoria across Ethiopia have developed their own distinctive practices and preferences. Some regions are known for particularly fine parchment, while others are noted for specific techniques or styles. The regional variation reflects both local resources and the transmission of knowledge through apprenticeship networks.

d. Sustainability and Sourcing: The Ecological and Economic Dimensions

The production of parchment has significant ecological and economic dimensions. The use of goatskins for parchment production is closely tied to the pastoral economy of the Ethiopian highlands. The Hamere Berhan Institute, for example, receives its goat skins from local donors who slaughter animals on feast days (VOA Africa, 2023). This practice integrates parchment production into the broader patterns of livestock husbandry and religious observance.

The sustainability of parchment production depends on the continued availability of high-quality skins and the transmission of traditional knowledge. As one Ethiopian priest observed, "Ancient parchment manuscripts are disappearing from our culture, which motivated us to start this project" (VOA Africa, 2023). The precious works are kept mainly in monasteries, where prayers or religious chants are conducted using only parchment rather than paper manuscripts; however, "this custom is rapidly fading" (VOA Africa, 2023). The economic dimensions of parchment production are significant. The Hamere Berhan Institute produces manuscripts to order, with most manuscripts commissioned by individuals who then donate them to churches

or monasteries (VOA Africa, 2023). Some customers order small collections of prayers or paintings to have reproductions of ancient Ethiopian works (VOA Africa, 2023). The production of a single manuscript represents a substantial investment of time and resources: "Small books can take one or two months. If it is a collective work, large books can take one to two years. If it's an individual task, it can take even longer" (VOA Africa, 2023).

IV. Result and Discussion

4.1 The Chemistry of Ink and Pigment – From Earth to Image

a. The Dual Tradition: Ink and Pigment as Parallel Chemical Traditions

The preparation of inks for writing and pigments for painting in Ethiopian sacred arts represents two parallel but interconnected chemical traditions, each requiring distinct materials, techniques, and knowledge systems. While inks were primarily formulated for the precise application of text onto parchment surfaces, pigments were developed for the broader application of color in manuscript illuminations, icons, and wall paintings. Both traditions, however, share fundamental principles: the transformation of raw natural materials; soot, minerals, plants, and earths into stable, durable, and visually powerful substances through processes of grinding, mixing, heating, and binding.

The Ethiopian tradition of ink and pigment making is continuous since at least late Antiquity and serves as "an important source for analogies to those who wish to better understand vanished historical practices" (Winslow, 2016, p. 25). Despite this continuity, only few studies on Ethiopian inks and pigments have been conducted, and no original written ink recipes have been transmitted (Hamburg University, n.d.). The knowledge of ink and pigment preparation has been preserved primarily through oral tradition and apprenticeship, with scribes and painters learning their crafts through direct instruction and practical demonstration.

Ethnographic research has documented the survival of these ancient techniques into the modern period. Scribes in Andabet, south of Debre Tabor, continue to make their own black ink from carbon, typically soot from the bottom of cooking pots mixed with starchy liquid from infused cereal grains to bind it (Mellors, 2009). The mixture is stirred every day for at least three months until a skin is formed which is skimmed off and dried into blocks; the blocks are then reconstituted with liquid to form the ink as and when required (Mellors, 2009). This painstaking process, requiring months of daily attention, reflects the devotion and patience that characterize Ethiopian sacred craftsmanship.

b. Black Inks: Carbon-Based and Iron-Gall Traditions

Carbon-Based Ink

The most common black ink in Ethiopian manuscript production is carbon-based, made from soot or lampblack mixed with a binding agent. The primary ingredients are carbon, gum arabic, and water (Textual Criticism, 2017). Carbon is gathered by interrupting a flame from a lamp or candle with a metal surface, producing a fine black powder (Textual Criticism, 2017). In the Ethiopian tradition, the carbon source is typically soot from the bottom of cooking pots (Mellors, 2009).

The binding agent serves to suspend the carbon particles and adhere them to the parchment surface. In Ethiopian practice, the binder is a starchy liquid from infused cereal grains (Mellors, 2009). The chemistry of this process involves the dispersion of carbon particles in a colloidal suspension, stabilized by the polysaccharides present in the starchy binder. The mixture is stirred daily for at least three months until a skin forms, which is skimmed off and dried into

blocks (Mellors, 2009). This extended period of stirring allows for the complete dispersion of the carbon particles and the development of a stable, uniform suspension. The blocks are then reconstituted with liquid to form the ink as needed (Mellors, 2009).

Modern reconstructions of carbon-based inks have used lamp black (5 g) mixed with gum arabic solution (5 g untreated gum arabic in water) to create an intensely black ink (Early History of the Codex, 2023). The gum arabic, a natural exudate from Acacia trees, acts as a hydrocolloid, providing both binding and stabilizing properties. The carbon particles, being essentially pure elemental carbon, are chemically inert and resistant to fading, contributing to the remarkable permanence of carbon-based inks.

c. Red Ink (Qəne): The Chemistry of Sacred Color

Red ink, known as qəne in Ethiopian tradition, holds a special place in manuscript production, used for sacred names, headings, and marginal notes. The use of red for these purposes reflects the theological significance of the color, associated with the blood of Christ, martyrdom, and divine power.

Sources of Red Pigment

Red pigments for ink and painting were derived from multiple sources. Red ochre (hematite, Fe_2O_3) was the most common source, readily available from natural earth deposits. Hematite, an iron oxide mineral, produces a stable, opaque red color that is chemically inert and resistant to fading. Red ochre was widely available in Ethiopia, with red soil being a readily accessible source of pigment (Mellors, 2009).

Cinnabar (mercuric sulfide, HgS), a more expensive and toxic red pigment, was also used, though less commonly due to its cost and the dangers associated with its preparation. Cinnabar, the most common ore of oxidized mercury found in nature, was the most widely used red pigment around the globe (The Met, 2018). Its use in Ethiopian manuscripts suggests connections to broader trade networks that brought imported pigments to Ethiopia.

Organic reds, derived from insects such as cochineal or from plants such as madder, were also employed. These organic pigments, while less stable than mineral pigments, offered vibrant hues that were valued for their aesthetic qualities.

d. Pigments for Illuminations and Icons

The production of illuminated manuscripts, icons, and wall paintings required a diverse palette of pigments derived from minerals, plants, and imported sources. The technical study of Ethiopian paintings has revealed the use of a wide range of pigments, reflecting both local availability and international trade connections.

Sources of Color

White pigments were derived from kaolin (white clay), gypsum (calcium sulfate), and lead white (basic lead carbonate). In Aksum, there are not only supplies of white clay but also red soil to make paint (Mellors, 2009). The preparatory layer of some Ethiopian wall paintings was composed of dolomite, clay rich in clinochlore, and sand, in contrast to the more common gypsum and calcite (Gebremariam et al., 2015).

Red pigments included red ochre (hematite), cinnabar (vermillion), and organic reds. The use of cinnabar and orpiment (arsenic sulfide) is quite frequent in Ethiopian masterpieces (Wion,

2004). These pigments, often imported, were part of the international luxury goods trade of the time (Wion, 2004).

Yellow pigments were derived from yellow ochre (goethite, FeO(OH)) and orpiment (arsenic trisulfide, As_2S_3). Orpiment, a toxic but brilliantly colored pigment, was used frequently in Ethiopian paintings (Wion, 2004). Its use reflects connections to trade networks that brought imported pigments to Ethiopia.

Blue pigments included indigo (from plants), smalt (cobalt-colored glass), and ultramarine (from lapis lazuli). The Ethiopian magic scrolls, traditional parchment artifacts used by Christians of Ethiopia as protection against disease and demonic possessions, have been the subject of combined analysis using Infrared Reflectography (IRR), Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy, and Ion Beam Analysis (IBA) to characterize inks and pigments (Vadrucci et al., 2023). Analysis of the Garima Gospels has revealed the use of lapis lazuli as a blue pigment, indicating the import of this珍贵 material (Gebremariam, 2016).

Green pigments were derived from malachite (copper carbonate hydroxide), verdigris (copper acetate), and mixtures of blue and yellow pigments. The main green in some Ethiopian manuscripts is a mixture of a peculiar copper green with lime white and smaller amounts of carbon black (Gebremariam, 2016). Vergaut obtained using orpiment and indigo, is the main green in some illuminated manuscripts (Grigoryan, n.d.).

4.2 The Art of Illumination Visual Theology and Technical Mastery

a. The Painter as Theologian: Visual Exegesis in Ethiopian Orthodox Culture

In Ethiopian Orthodox tradition, the painter occupied a position far exceeding that of a mere decorator or craftsman. The painter was understood as a visual exegete, one who interpreted sacred narrative through the medium of image, translating theological truth into a form accessible to the faithful. As Marilyn Heldman acknowledged in 1994, "documentation of Ethiopian workshop practices is nonexistent" (French, 2025, p. 2), yet the paintings themselves testify to the profound theological sophistication of their creators. The earliest extant Ethiopian icon paintings date from the early fifteenth century, after Emperor Zärʾa Yaʿəqob (r. 1434–1468) promoted the veneration of the Virgin, decreeing that every church have a dedicated altar to Mary (French, 2025). This imperial patronage created a sustained demand for painted icons and established the painter as a figure of considerable spiritual and cultural significance.

The painter's role was fundamentally theological. As Heldman (1996) demonstrated in her study of the Marian icons of the painter Fre Seyon, Ethiopian artists were not merely illustrators but theologians working in the visual medium. Fre Seyon, a monastic artist active during the reign of Zärʾa Yaʿəqob, signed his works and infused them with sophisticated theological meaning (Heldman, 1996). The painter, like the scribe, engaged in work that was both technical and devotional, an act of worship that made the practitioner "worthy in the eyes of God" (VOA Africa, 2023). The integration of artistic skill and spiritual devotion is a defining characteristic of Ethiopian sacred painting.

b. Iconographic Conventions: The Visual Language of Ethiopian Sacred Art

Ethiopian sacred art developed a distinctive visual language characterized by specific iconographic conventions that conveyed theological meaning through form, color, and composition. These conventions, while drawing on Byzantine and Coptic precedents, evolved into something uniquely Ethiopian.

The Frontal Gaze: Spiritual Connection through the Eyes

The most immediately recognizable feature of Ethiopian painting is the treatment of the human figure, particularly the eyes. Figures are typically depicted with large, almond-shaped, penetrating eyes that establish direct visual contact with the viewer (Wikipedia, n.d.). This frontal gaze is not merely a stylistic convention but carries profound spiritual significance: the eyes serve as windows to the soul, establishing a direct connection between the viewer and the divine figures depicted. Ethiopian art is characterized by simple forms, bold outlines, vibrant colors, and frontal figures with large eyes (Annenberg Learner, 2019). The direct, frontal gaze of the figures invites the viewer into immediate spiritual communion, collapsing the distance between the earthly and the heavenly realms.

V. Conclusion

Synthesis of Findings

This study has examined Ethiopian sacred metalwork and manuscript arts as a sophisticated indigenous chemical tradition—a form of applied alchemy in which practical chemistry, ritual practice, and theological symbolism were inseparably fused. The evidence presented across the preceding sections demonstrates that Ethiopian artisans possessed an empirical understanding of materials and their transformations that was transmitted across generations through apprenticeship and oral tradition, and that this knowledge was deeply embedded in the spiritual life of the Ethiopian Orthodox Tewahedo Church.

The argument advanced in this study that Ethiopian sacred arts constitute a form of applied alchemy rooted in indigenous chemical knowledge, finds support in the material evidence. As Loubser and Le Roux (2021) have demonstrated in their investigation of a century-old Ethiopian prayer scroll, the application of analytical techniques such as X-ray fluorescence spectroscopy and technical photography can reveal "a whole new layer of information" that adds to the aesthetic and spiritual impact of the work (p. 4). The authors suggest that this "alchemy", the materiality of spiritual expression in artistic creation can reveal aspects of which even the artists themselves may have been unaware. This finding resonates with the Ethiopian tradition, in which the technical knowledge embedded in sacred making was often transmitted implicitly through practice rather than codified in written recipes.

The Legacy of Ethiopian Sacred Arts

The traditions of Ethiopian sacred making have survived into the modern period, though they face significant challenges. The Hamere Berhan Institute in Addis Ababa, founded to preserve ancient manuscript traditions, continues to produce manuscripts using methods dating back to early Christianity (The Guardian, 2025). Since its founding, the institute has produced approximately 315 manuscripts, painstakingly crafted on goat skin using homemade bamboo pens, inks made from soil and plants, and paints enriched with acacia wax. Scribes continue to copy texts from paper to parchment, believing that parchment manuscripts "will last a long time if we protect it from water and fire". One scribe expressed the hope that "in 1,000 years, or more, people will find the books I wrote".

However, these traditions are increasingly threatened by political and economic changes. The incorporation of Ethiopia into the modern state and increasing international trade has led to a radical decline in the importance of local metalwork. Traditional politics were dismantled as areas were brought under national rule, and "the power of the smiths suddenly became irrelevant as the new rulers did not rely on their technology". The production of gold and silver insignia was no longer necessary, and spears became useless in the presence of modern firearms. The

influx of scrap metal from motor vehicles and other international imports led to the end of smelting and the smiths' monopoly of iron (Freeman, n.d.). Modernization and foreign products threaten traditional blacksmithing practices and economic viability, with the younger generation showing declining interest in smithing, risking the extinction of this ancient craft

Ethiopian monasteries have played a crucial role in preserving and transmitting manuscript knowledge. The precious works are kept mainly in monasteries, where prayers or religious chants are conducted using only parchment rather than paper manuscripts. Ethiopian manuscript production and preservation occur traditionally in the nation's monasteries and churches, and the vast majority of the works contained in these collections are religious books that reflect the attending concerns of these institutions. Monks and priests serve as both knowledge carriers and custodians of heritage, transmitting the skills of manuscript production across generations

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