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Article

Michael Scot and the Augustalis Gold Coins

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Abstract:

Herein is shown Michael Scot's potential involvement in the minting of the Augustalis gold coins introduced by the Holy Roman Emperor Frederick Hohenstaufen II in the early thirteenth century. Michael Scot was definitely helpful in two aspects: measure and calculations. Additionally, it is shown how his knowledge of alchemy could have been helpful in metallurgical issues such as gold extraction and purification, suggesting that the 13^{th} century experienced a prototypical "entrepreneurial alchemy" that preceded Newton's use of alchemy for the British Mint, centuries later.

Keywords: Medieval History; Artisanal Gold Mining; Alchemy

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Introduction

This article is part of a series of papers intended to shed light on the 13th century "wizard" known as Michael Scot (T. C. Scott and Marketos 2014a). He was a well-educated man for his time with knowledge in principally:

- Medicine
- Mathematics
- Astrology/Astronomy
- Alchemy

and complementary interests in meteorology and music. Recognized primarily for translating scholarly works from Arabic to Latin (Thorndike 1965; Charles H. Haskins 1927; Burnett 1994), the contributions of Michael Scot have been underestimated. We cite a few that have only come to light recently:

Medicine:

A very detailed description in Latin concerning the medical case known as "Mary of Bologna" was finally understood in the early 1970s to be a very rare case of miscarriage or

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"spontaneous abortion", not followed by immediate expulsion, of twin embryos, dead at different dates and calcified (O'Neill 1973, 1974). In short, Scot had actually recorded, back in the 13th century, a rare medical case, and this had not been fully appreciated until the 20th century.

Mathematics:

An analysis on the origins of the Fibonacci numbers (T. C. Scott and Marketos 2014b) suggests that Michael Scot may have played a role in the formulation of the Fibonacci sequence, which would explain why Leonardo de Pisa dedicated the second version of his famous book "Liber Abaci" to him.

Meteorology:

Michael Scot provided a description of four parallel rainbows in the sky (Thorndike 1965, 69) and a recent analysis (Tony C. Scott 2017) has shown that quaternary rainbows and various types of multiple rainbows have been observed.

Astronomy and Music:

Kepler's contribution involving the "Music of the Spheres" can be traced back to Pythagoras through Michael Scot. We find therein ideas associating music with astronomy. In particular, the Fibonacci numbers, found by Scot's colleague, Leonardo de Pisa, play a significant role in this context. Scot's work was a precursor to the astronomical phenomena known as *"orbital resonances"* (T. C. Scott and Harper 2023).

Although recent work has shed light on Scot's various contributions, what still remains shrouded in mystery are his contributions to alchemy. Scot's writings in alchemy include (Brown 1897, XIV):

Liber luminis luminum

("Book of light") which Scot is said to have translated into Latin (Brown 1897, 81–89).

Ars Alchimia

("The Art of Alchemy") associates metals with planets, e.g. the transformation of Venus into the Sun, Mercury (mercury) into silver and lead into gold, the nature of salts, etc … (Minio-Paluello 2025; Thomson 1938) (Brown 1897, 88–94).

Quaestio curiosa de natura solis et lunae

("A curious question about the nature of the sun and moon") uses the metal/planet association and considers gold and silver (rexresearch 2025)

These medieval manuscripts have been examined at length by, for example, Charles Haskins (Charles H. Haskins 1927, 1928) but part of the mystery surrounding Scot is due to the great divergences amongst scholars, making it difficult to express a categorical opinion on the real work of Michael Scot. According to Haskins:

> The court of Frederick II became a peg on which to hang all sorts of fictitious attributions and Scot's popular reputation could easily lead to connecting his name with the works of others. So of Scot as an alchemist it is hard to speak with any certainty amid the mass of false attributions which accompany the alchemical

> literature of the later Middle Ages … That he passed as an alchemist is clear from the ascriptions of several manuscripts, notably a list of alchemical writers preserved in a Palermo codex, and his familiarity with alchemical doctrine is seen in the chapter from his own "Liber Particularis" … The question is whether he wrote actual treatises on the subject, and, if so, whether any of these can be identified. A definite answer must await the sifting of the confused and uncertain manuscript material. (Charles H. Haskins 1927, 280)

For instance, J. Wood Brown doubts Michael Scot is the true author of the "Quaestio … lunae" (Brown 1897, pp.77–78). Thorndike remarks of the "De alchemia" manuscript at Oxford dedicated to "the great Theophilus, king of the Saracens" rather than to [Scot's benefactor] the Emperor Frederick Hohenstaufen II, that:

> Michael Scot mentions himself by name in it rather too often for us to accept the treatise as his without question … while the allusions to 'Brother Elias' … as a fellow worker in Alchemy are perhaps also open to suspicion. (Thorndike 1929, 334)

Note that S. Harrison Thomson disagrees with Thorndike on this last point (Thomson 1938, 523–24) showing a lack of unanimous consensus. Haskins and Thorndike are two of the most authoritative scholars on Michael Scot, with Thorndike having a high opinion of Michael and Haskins insisting that he is overrated. In spite of their scholarship in analyzing historical records and medieval manuscripts, neither author is perfect: Haskins misunderstood the medical case of Mary of Bologna and Thorndike did not quite grasp the scenario of multiple rainbows because of their lack of scientific knowledge in these respective fields (T. C. Scott and Harper 2023, 4).

This article is neither a survey of Michael Scot's writings related to alchemy nor an elaborate inquiry into esoterism. Rather, we attempt to discern through historical analysis, Michael Scot's contributions to alchemy, *beyond the scope of historical records*.

Alchemy vs Chemistry

Alchemy's development is often linked to the earliest practices of metallurgy, which date back to the Neolithic period. It is generally accepted that alchemy is an "ancestor" of modern chemistry, but the genuine practical contributions of alchemy have been overshadowed by the associated mysticism, and by the late 1800s, alchemy was thoroughly discredited, that even mentioning it was a career-limiting move. While this gave Rutherford (the "father of nuclear Physics") and Soddy pause before announcing transmutation to the world, they knew their observations were based on empirical evidence, not mysticism. Nonetheless:

1. A number of chemical elements were discovered by alchemists. We mention:
    a. Phosphorus was the first element to be "discovered", in the sense that it was not known since ancient times (Weeks 1932). The discovery is credited to the Hamburg alchemist Hennig Brand in 1669 CE, who was attempting to create the fabled philosopher's stone (Beatty 2000).
    b. During the Bronze Age, arsenic was melted with copper to make arsenical bronze (Charles 1967) but by 1250 CE, Albertus Magnus (Albert the Great) isolated the element by heating soap together with arsenic trisulfide (Emsley 2001).

2. The transmutation of base substances into gold is now known to be impossible by means of traditional chemistry, but possible by other physical means. Although not financially worthwhile, gold was synthesized in particle accelerators as early as 1941 (Sherr *et al*. 1941).

   Alchemists thought of mercury as the "First Matter" from which all metals were formed and with sulfur, the essential link to the creation of gold (Stillman 2003, 7–9). What is interesting is that mercury is right next to gold on the periodic table and yes, and if subjugated to nuclear bombardment, will generate gold but the isotope of the latter is unstable and the process costs more than the value of the gold itself.

3. Medieval alchemists would pour sulfuric acid (H_2SO_4) on salt ($NaCl$) to produce hydrogen chloride (HCl) in the form of a virulent gas over the salt itself, according to the (modern) chemical equation:

   $$NaCl + H_2SO_4 \rightarrow HCl + NaHSO_4$$

   Medieval alchemists called this gas the "Spirit of Salt". Today, we would consider that notion silly but the middle ages is the "*prehistory*" to science. This image nonetheless had the useful merit of retaining a marker, a picture for the process. There are still references to the spirit of salt in old chemistry textbooks and even modern dictionaries (Farlex 2025), demonstrating that there are still traces of alchemy in modern chemistry.

4. Sir Isaac Newton's alchemical writings remained largely hidden and unknown until their reemergence in 1936. These materials were considered "unfit to publish" by Newton's estate at the time of his death and considered unworthy of one of the greatest Physicists of all time by the scientific community for many decades afterwards. However, modern scholarship has revealed that Newton's analysis and resynthesis of white light owes a debt to corpuscular alchemy (Newman 2010). In his "Hypothesis of Light" of 1675, Newton posited the existence of the ether to transmit forces between particles. His notion of the ether was almost isomorphic with occult forces based on Hermetic ideas of attraction and repulsion between particles. His contributions to science cannot be isolated from his interest in alchemy (Westfall 1981, 530–31).

The transition of alchemy to chemistry is actually more continuous and complex than conventional wisdom admits. From the past to the present, one is dealing with a "protochemistry" with connections to metallurgy, cosmetics, pharmacology, fermentation, ceramics and dyeing (Hoffmann and Torrence 1995, p.78). With these points in mind, we now examine the circumstances of Scot's setting.

Historical Setting

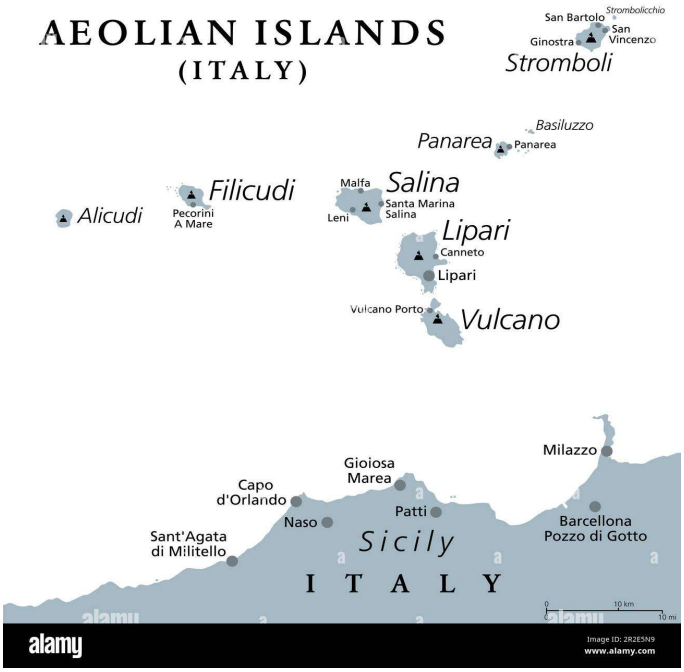
Lipari Islands

Frederick Hohenstaufen II, ruler of the Holy Roman Empire, posed a series of questions to Michael Scot (Charles H. Haskins 1922b, pp.689–691) covering topics like the foundations of the earth, the heavens, and the soul including inquiries about the nature of God's abode, the locations of hell, purgatory, and paradise. He also questioned Michael Scot about the nature of volcanoes, rivers, seas and other natural phenomena. Michael Scot's reply contains much typical geographical lore of the Middle Ages. Particularly noteworthy is the description of the hot springs, volcanoes, and sulfur beds of Italy, Sicily, and the Lipari Isles (also known as the

Aeolian islands), the text of which is given by Charles Haskins (Charles Homer Haskins 1921–1922a, pp.272–274). Figure 1 shows a map of the Aeolian Islands. Michael Scot specifically mentioned by name the islands: Stromboli, Vulcano, and the island of Lipari, all part of the Kingdom of Sicily. Michael's knowledge of the Lipari group does not necessarily rest on personal observation; it at least represents inquiry among those who have observed (Stevenson 1923, p.141). From Thorndike's statement:

> Scot would seem skeptical as to the transmutation of metals … Yet another statement that, where heat and sulphur abound, underground 'gold grows and is born' …" (Thorndike 1965, 111)

We can infer that Scot made no claims that he could change baser metals into gold, rather he realized the insides of the Earth provided their own "alchemical pot" producing gold, lead and silver.



Aeolian Islands - Courtesy Alamy.

Thus, if one found out how the earth made gold (T. C. Scott and Marketos 2014a), one might be able to reproduce it by accessible chemical means. Naturally, if nature hid her secrets deep within the bowels of the Earth, the answer could be found by probing those depths and witnessing the production of metal within the Earth itself. The closest Michael Scot could do in this regard in his time was to look into the mouths of volcanoes. Clearly, that was part of his goal in his exploration of the Lipari (or Aeolian) Islands. Scot's idea is not without merit and is vindicated in modern terms. Where seismic activity is present in the form of volcanoes, earthquakes, and hot springs, one often finds gold (Department of Geosciences 2025; He *et al.* 2024; Miller 2024; Meeker *et al.* 1991), as in the case of the California gold rush and the Klondike gold rush. However, we need to determine how feasible this notion was in the Kingdom of Sicily ruled by the emperor Frederick II.

Geological Resources in the Kingdom of Sicily

We need to assess the mineral possibilities relevant to the whereabouts of Michael Scot during his time with Frederick II. Mindat.org (Hudson Institute of Mineralogy 2025), the world's largest open database of minerals, rocks, meteorites and the localities they come from, lists two localities for gold in the Kingdom of Sicily:

1. La Fossa crater, Vulcano Island in the Lipari Group associated now with the city of Messina, Sicily. This island is near the big Lipari island, as shown in Figure 1.

2. Mount Somma ("summit") located in the Province of Naples, an ancient volcano in the Somma-Vesuvius volcanic complex which is now partially surrounded by the younger cone of Mount Vesuvius. Note that Mount Somma's *caldera*, which is a large volcanic depression, does indeed resemble an alchemist's cauldron.

Apparently, Mount Etna also has some gold in small amounts (Musumeci 2025) but according to Haskins (Charles H. Haskins 1927, p.298), Scot has no "special account of Etna". Neither does Scot mention Vesuvius or Mt. Somma. Nonetheless, the thesis that gold can be found in places with a record of seismic activity holds up in the surroundings of Michael Scot in the Kingdom of Sicily, although that very same seismic activity can discourage human settlement nearby. Since the terrible volcanic eruption of Vesuvius in 79 CE which destroyed Pompeii and Herculaneum, understandably, people only slowly returned to the area over the centuries. Additionally, the Lipari islands also have pumice, obsidian, sulfur, alum (aluminum sulfate) which can be extracted from Vulcano. It should be noted that the so-called "Conca d'Oro" (golden Basin) recognized by the Arabs in Palermo, Sicily never had gold. Rather, it was a reference to a lush fertile landscape, especially its orange and citrus groves, and was named for the abundance of these crops. The "gold" refers to the value and abundance of the agricultural produce, not actual gold deposits. The natural gold or mercury deposits in the Kingdom of Sicily don't seem to be abundant. Thus, we have to look elsewhere.

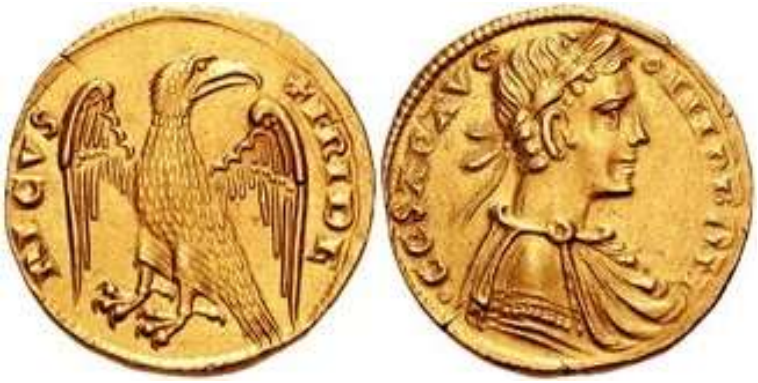
In the case of silver, Mindat.org provides a number of sites in Italy, two of which are geographically in the former Kingdom of Sicily:

1. Valanidi Argentiera, Motta San Giovanni, Calabria.
2. Palinuro Seamount, Aeolian Arc seamounts, Southern Tyrrhenian Sea.

Much like gold and silver, cinnabar generally occurs as a vein-filling mineral associated with volcanic activity and hot springs. Cinnabar was a valuable pigment, used for its deep hue and other desirable qualities (Coccato *et al.* 2024). A process for making synthetic vermilion (a pigment derived from cinnabar) was developed in antiquity, with methods involving heating mercury and sulfur (Spindler 2018). The Levigliani and Ripa mines have mercury/cinnabar deposits but these mines are in the Apuane Alps in (Upper) Tuscany (Dini *et al.* 2001) and thus outside the Kingdom of Sicily. Mindat.org gives us for sources of mercury: (i) Allumiere Quarries and (ii) Castagneto La Trinità. Both places are in Allumiere, Lazio, Italy, to the North of Rome. Although, parts of Lazio were in the Kingdom of Sicily at some stage, these mercury sources would be beyond the reach of Frederick II during his reign. Mindat gives other sources in Lombardy and Sardignia but these are also outside the purview of the Emperor's reign.

There are online claims that the red rocks of Pantelleria island contain cinnabar. However, the reddish color in the case of hematite is due to iron oxydation and the red-brown cossyrite (aenigmatite) is a mineral containing iron (Washington 1913, p.687). More information can be obtained by looking at major events in the life of the Emperor Frederick Hohenstaufen II.

The Augastalis gold Coin



Augustalis Coin:
Example of a Neapolitan Augustale, showing a Roman Emperor
Courtesy Wikipedia

Around 1229-1231, after Frederick II returned from the 6^{th} crusade to the Kingdom of Sicily, he introduced a new gold coin, the *Augustalis* (Abulafia 1992, 222). The Augustalis, shown in Figure 2, was patterned after the ancient Roman coin "Aureus" and was minted until his death in 1250. It has the highest quality in craftsmanship, aesthetic appeal and precise weight. These coins were among the first gold coins minted and of commercial importance in Western Christendom after the disappearance of the old Roman Imperial coinage (Grierson and Travaini 1998, 455).

These high-quality coins were much appreciated in Europe because they were better made. Not until the Renaissance was that level of craftsmanship or precision reached again. It was good for the economy and introduced a gold standard of sorts:

> The reintroduction of gold coinage in the Western Europe, in fact, represents a kind of mystery per se. In central and western Europe, the coinage remained essentially monometallic (based on silver) for about five centuries, after the monetary reformation of Charles the Great in 798 [CE] introducing the new silver denarius that will become the standard currency in western and central Europe. (Baldassarri *et al*. 2014, 4)

However, conventional wisdom would have it that Sir Isaac Newton first introduced a gold standard, in the British Mint (Eichengreen 2019), centuries later. The Augustalis coins were minted in the Kingdom of Sicily, but this begs the question: if there is not much gold in Sicily or the Lipari islands, where did Frederick Hohenstaufen II get his gold from? The answer is North-Africa! Peter L. Bernstein states:

> At the time of Frederick's death, Sicily was operating with two concurrent gold standards. One was the *Tarì*, which had Arabic roots and had been in use since the ninth century. Although the Tarì had gone through some debasement over the years, from the early twelfth century onward, it was stabilized at 16 carats of gold. This was better than the purity of the Byzantine solidus at that time and established it as one of the most stable in Europe. The coins were stamped out in a variety of sizes and tended to circulate on the basis of their weight rather than their face value. The Tarì enjoyed such wide circulation that it became a kind of unit of account by which many items were priced.

> Frederick II considered the Tarì unimpressive and too irregular for the homeland of a Holy Roman Emperor of his exalted status. After a military victory against the Tunisians in 1231, he was assured of a substantial annual tribute in both gold coin and gold dust from the West African gold sources. Now Frederick's imperial mints began to strike a new gold coin called the 'Augustalis'. Robert Sabatino Lopez describes the Augustalis, with its classical eagle imprinted on one side and the emperor's laureate head on the other, as "a startling advertising medium" and a dramatic contrast to the formless Tarì. The Augustalis was minted in 20 $^1/_2$ carats and weighed 5.28 grams, which gave it greater value than the Arab dinar. This impressive coin soon eclipsed the Tarì and was in strong demand throughout western Europe and the Near East. (Bernstein 2001, 90)

We can see that Frederick's gold was mostly tribute from Tunisia, although some of his gold was likely bounty from his crusade. The quote mentions the earlier Tarì coin (Cardini 2001, p.26). These Tarì coins were generally minted from African gold obtained from Misrata or Tunis in Northern Africa in exchange for grain. Frederick's maternal grandfather, Roger II of Sicily, issued such coins, becoming the only Western ruler at that time to mint gold coins. Their composition was 16 $^1/_3$ carat gold (0.681 fineness) with some adjunction of silver and copper. At 20 $^1/_2$ carats (854/1000), the Augustalis purity equaled that of the Byzantine "hyperpyron" coin. Its fine gold weight of 4.54 grams matches the contemporary Islamic double dinar of the Tunisian Hafsids. With its weight and title, the Augustalis was adapted to exchanges with both worlds, Islam and the Byzantine Empire. The question arises: how was Michael Scot involved in all this?

Weights, Measures and Gold Purification

Concerning Michael Scot's contributions, a big part of the answer comes from Mario Rosario Zecchino:

> We have already seen how the tendency towards the uniformity of weights and measures was typical of each established power, in order both to support the kingdom's trade and to demonstrate competence within the territory ruled. Frederick's concern with these issues was an aspect of his well-known inclination to involve himself in all matters. We know that leading scientists and scholars were asked to clarify for him how to measure the heights of towers and mountains. To satisfy his curiosity, great scientists, such as Michael Scot and Leonardo Fibonacci, were obliged to undertake difficult calculations using the astrolabe. The first of these calculations, recorded in Scot's Liber Introductorius, refers to other tools for measurement, such as the abacus, the perch divided into ten feet, and the scales. In another work, Astronomia or [Scot's] Liber Particularis, dedicated to 'Frederick emperor of Rome', Scot clearly refers to the compass …the third book of Frederick's Constitution laid down three specific rules on weights and measures …" (Zecchino 2017, 255)

These strict rules of weight and measure were applied to everyone, i.e., sanctions against counterfeiters and ensuring none of the King's subjects were cheated. We can see that Frederick II put his scholars to good work! Leonardo Fibonacci's famous book on Mathematics "Liber Abaci" which introduced the Hindu numbers and provided many applications of these numbers to commerce, was dedicated to Michael Scot himself (T. C. Scott and Marketos 2014b). This clearly played a role in the Emperor's goals. The question arises: how did Frederick II ensure the high grade purity of his coins? This is where Michael could have played an additional role, very much along his abilities as an alchemist. To find out

more, we need to look at his writings. According to Peter Bonus, Michael's "Quaestio …lunae" states:

> Many have said that this first substance of gold is sulfur and mercury. But sulfur and mercury are metals distinct from gold, and are not found where gold is found." (Bonus 2010; rexresearch 2025)

The latter statement is not quite true but it could well have been Michael's experience. It would help rationalize why he could find sulfur and perhaps mercury in the Lipari islands but not gold.

> In the second place, some enquirers, who observed the ease with which gold absorbs mercury, were surprised to find that this mercury, though highly purified, did not perfect the gold into the Tincture.
>
> (…) gold itself is altogether mineral, as is clearly apparent from its weight, and the ease with which it absorbs mercury. (Bonus 2010; rexresearch 2025)

We can take this as admission by Michael that if you mix gold with mercury, you don't get more gold. That is chemically impossible. Otherwise, the dream of alchemy would have been long realized. It is more accurate to say that gold and mercury form an *amalgam*, a mercury alloy, as the process is not dissolution in the traditional sense. This process is used in gold mining to extract gold from ore, and the resulting gold-mercury amalgam can be separated to recover the gold. In 13th century Europe, methods of gold purification included:

Cupellation:

This involved heating gold ore with lead in a furnace, allowing impurities to oxidize and be absorbed by a porous material, leaving behind purer gold (T. Rehren and Eckstein 2002, 445–448). The primary tool for small-scale cupellation was the *cupel*, a small vessel shaped in the form of an inverted truncated cone, made of bone ashes.

Cementation:

This is a type of precipitation that used salt to separate gold from silver alloys, drawing out silver and leaving a higher concentration of gold. Salt cementation has been used for "gold parting" which is the separation of gold from silver. Gold and silver are often extracted from the same ores and are chemically similar and therefore difficult to separate. Parting is a process by which gold is purified to a commercially tradeable standard, typically $\geq 99.5\%$. Removal of silver is of particular interest since the two metals often co-purify. Gold parting can be traced as far back as the 6^{th} century BCE (T. Rehren 2003, 207).

Mercury Amalgamation:

Mercury is mixed with gold-containing materials, forming a mercury-gold amalgam which is then heated, vaporizing the mercury to obtain the gold. Since mercury binds to the gold, the latter is separated from the ore and other impurities. However, it is very hazardous: mercury vapors can poison, kill, and even mutate organic life. This brings us to the topic of *Artisanal mining* (IGF 2024) using mercury. It is ancient and can be traced back to Roman times (geology.com 2023; Johnson 2024). In many countries today, elemental mercury is still used in *Artisanal and Small-scale gold Mining* (ASGM). However, the ancient Roman times recognized mercury's toxicity, specifically in mercury mines; they didn't have the advanced

understanding of ventilation or protective equipment we have today. They did, however, utilize techniques like confining the process within closed vessels to help contain mercury fumes and prevent widespread exposure.

Michael Scot knew about alums, salts, mercury, and thus had the practical (alchemical) knowledge needed to use any of these methods. Note that alums were used in medieval times for metal refining (Brown 1897, p.86), specifically in a gold parting process known as "acid parting" used for gold and silver (Bayley 2008, p.145) (Craddock 2000, p.69). Although cementation or cupellation are the most likely methods used for the Augustalis gold coin, archaeology has nonetheless revealed an early Islamic method in the West African site of Tadmekka, in the Republic of Mali, where glass is used to purify the gold (Th. Rehren and Nixon 2014; Leotaud 2019). The Saharan trade route links Tadmekka to Tunis, and it becomes tantalizing if this method was considered.

It is not entirely certain where the purification of gold was done in North Africa or Sicily although we do know that the minting of the Augustalis gold coins was done in Messina, Sicily and Brindisi, Apulia and Naples in Southern Italy, all of which were part of the Kingdom of Sicily (Perfetto 2025). Thus, the geographical proximity of Mt. Somma with its gold to the mint in Naples is also tantalizing but so far, we have not found any historical record of such a link between the two.

A detailed chemical analysis of the Augustalis coin beyond what has been done already, could reveal the extraction or purification method, although X-ray analysis of some 15 Augustalis coins has revealed that its major impurity is silver and that "the variability observed in the compositions of the Tarì and Augustalis could suggest the reuse of Islamic and North African gold" (Baldassarri *et al*. 2014). The presence of silver is compelling. It could be derived from *electrum*, a naturally occurring alloy of gold and silver also known as "green gold" (Emsley 2001, 168) which has been known since ancient times. In such a case, gold partitioning would be needed. Then again, the presence of silver might be intentional, since silver is relatively more abundant, and the electrum is artificially made. While gold is valuable, it is also very soft. Adding silver to gold makes the resulting alloy harder, less susceptible to wear and tear, and easier to work with for striking coins.

Mindat tells us that naturally electrum can be found in the Montecatini mine (Caporciano mine) in Tuscany and the Amesmessa mine in the Guezzam Province of southern Algeria, thus ruling out natural electrum in the Kingdom of Sicily. However, electrum has been used for coins in Tunis since the ancient days of Carthage (Reis 2023) opening the possibility of minting existing coins from North Africa. Note that Haskins (Charles H. Haskins 1928) mentions the alchemical transformation of mercury, tin or copper into silver and in reality, silver is often found with lead, copper or zinc. Apart from gold and silver, the leading impurities of the Augustalis coin are respectively copper $(1.3 \pm 0.4\%)$, iron $(0.5 \pm 0.1\%)$ and lead (0.3%) (Baldassarri *et al*. 2014, Table 2). The total non-electrum impurity content of these Augustalis coins was only about $2.2 \pm 0.5\%$, surprisingly low, and much lower than the Tarì coins analyzed.

We have no actual proof that Scot was *directly* involved with the process of gold extraction and purification, with or without the use of mercury. Moreover, Mindat provides existing mineral resources. We cannot account for e.g. an ancient closed mine for which there are no historical records. However, given Frederick's use of his Arabic speaking scholars like Michael Scot as both messengers and cultural transmitters to Islamic foreign lands, it is more than likely that Michael Scot was consulted (as evidenced by Frederick's questions to Michael) especially in view of his knowledge of alchemy. Scot's involvement would make perfect sense and parallels Sir Isaac Newton's use of alchemy in his work on the (British) Mint (Marples 2022). Michael Scot was likely involved at some level especially with his experience with mercury in Toledo Spain. From J. Wood Brown, we have:

> If such a receipt is valuable as indicating the chemical practice of those days, it is no less interesting as it throws light upon the life and occupations of Scot. He must have set up a complete chemical laboratory at Toledo, with crucibles for the melting of metals, and alembics for the distillation of the substances which his art required him to mix with them. His situation was one very favorable to these pursuits, not only because Spain was one of those countries where the doctrine of alchemy made its greatest progress, and attracted most powerfully the concourse of foreign adepts, but also from the facility with which the necessary materia chemica could there be procured. The sierras of that country were full of mineral wealth of all kinds [including gold], especially quicksilver, which was one of the substances most frequently chosen to become the subject of the transmuter's art. (Brown 1897, 94)

There was indeed plenty of cinnabar in Spain and Michael knew about mercury well enough. The translation of Arabic texts concerning numerous disciplines including alchemy flourished in 12^{th} century Toledo, Spain, through contributors like Gerard of Cremona and Adelard of Bath (Holmyard 1990, 105–108). Moreover, Haskins reveals:

> Scot has been at Toledo, and if we can trust the preface, he dedicates his alchemy to a Saracen official of Tunis, and has been in contact with alchemists of other lands. All this points to an amount of cooperation and interchange which has not heretofore been noted in the field of alchemy… (Charles H. Haskins 1928, 358)

This assures us Michael Scot had the credentials, the experience and the network to be involved in developing the minting of the Augustalis coin.

Entrepreneurial Alchemy

Centuries later, alchemists would follow Scot's lead and explore the depths of the Earth. In central European mining operations, primarily in the 16^{th} and 17^{th} century, discoveries made in the early history of modern mining would be systematically combined with the alchemical knowledge of previous generations, especially in the thought of people like Paracelsus and Michael Sendivogius. Moreover, the alchemist's knowledge and experience with sulfur was very useful in the less esoteric world of metallurgy to determine the quality of metals, mining and of course the minting of coins.

Michael Scot's experience seems to be a precursor to the "entrepreneurial alchemy" used for mining and ore extraction that would come centuries later. According to Justin Sledge:

> By the mid-15^{th} and especially by the mid-17^{th} century, the figure of the alchemist was undergoing a tremendous tectonic change within the chaos of the Holy Roman Empire. A new type of alchemist was emerging. They labored in specially built labs that were state funded and bound by legal and financial contracts focusing on explicit quantitative results. They were subject to quasi-public analysis and vetting of their work and results and their career readily intersected with the birth of industrial mining and systematic metallurgy. These new alchemists grew out of the artisanal esoteric craft world of the middle ages somewhere between being a prophet and a proto-chemist to become integrated into the emergent pre-capitalist social economy as something truly modern. These were the entrepreneurial alchemists. (Sledge 2022)

Conclusions

In re-examining the alchemy attributed to Michael Scot, we have presented a feasibility study of the tasks requested by the Emperor Frederick Hohenstaufen II from Michael Scot related to the minting of his Augustalis Gold coin. The possibilities and inferences shown suggest a prototypical entrepreneurial alchemy that would predate the transition from alchemy to chemistry by many centuries.

The connections between alchemy and chemistry are not over. For instance, and to reiterate, Michael Scot identified gold with the Sun, as well a quicksilver with the planet Mercury. The Sun-gold identification works because gold has a relatively high atomic number (79) and consequently rare but surprisingly abundant nonetheless. It is believed most of the gold in the Earth's crust comes from the stars i.e. suns that have collapsed and went supernova and the remaining bits scattered via comet showers. The prevailing scientific belief is that gold was generated from a binary star system of neutron stars that merged and went "killer nova". However, the neutron star mergers theory alone cannot recently explain all the cosmic gold, particularly in older stars, because these mergers occur relatively late in galactic history and are infrequent (approximately once every 100,000 years) (Patel *et al*. 2025). This leaves open the possibility that perhaps the availability of Gold might be terrestrial after all, as Michel Scot or Sir Isaac Newton believed. Perhaps the Earth does create gold somehow through a "geo-alchemical" process, we don't yet understand.

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