

Case Report

# Artisanal Opal Mining in the Delanta Area of South Wollo, Northern Ethiopia

**Mamaru Genetu<sup>1,\*</sup> , Getahun Meseret<sup>1</sup> , Getnet Mewa<sup>3</sup> , Gera Techane<sup>1</sup> ,  
Solomon Zeleke<sup>1</sup>, Tatek Tadesse<sup>1</sup>, Ephrem Tilahun<sup>1</sup> , Meseret Aregahegn<sup>1</sup> ,  
Esubalew Yehualaw<sup>2</sup> **

<sup>1</sup>Mineral Industry Development Institute, Ministry of Mines, Addis Ababa, Ethiopia

<sup>2</sup>Ethiopian Ministry of Mines, Department of Geothermal Energy, Addis Ababa, Ethiopia

<sup>3</sup>Institute of Geophysics, Space Sciences and Astronomy, Addis Ababa University, Addis Ababa, Ethiopia

## Abstract

Ethiopia's opal mining and market sectors grapple with multifaceted challenges due to insufficient engagement from governmental and private entities. Key issues include the absence of comprehensive mining practices, limited promotional efforts, and the reliance on rudimentary techniques without proper machinery. Additionally, the market chain fails to adequately benefit local miners, exacerbated by fluctuating prices and the presence of illegal traders, unpredictability of the opal supply chain due to geological uncertainties. Environmental and social concerns loom large, worsened by the lack of impact assessments and miners' disregard for conservation efforts, posing risks to health, safety, and ecosystem stability. Demand for opals is shaped by a complex interplay of factors, including fashion trends, cultural inclinations, and economic conditions. Opal's historical appreciation for its fascinating play-of-color has cemented its status as a sought-after gemstone for jewelry and decorative purposes. Collaborative efforts are imperative to strengthen regulatory frameworks, improve promotional strategies, and foster sustainability in the sector. While mechanized mining offers efficiency gains, its implementation requires significant investment in equipment and infrastructure, primarily benefiting mining enterprises, establishing a centralized platform for grading opal at a designated location can streamline the process and foster a free-market system, attracting foreign investment and contributing to the country's economic development.

## Keywords

Beauty, Miners, Grade, Precious, Opal

## 1. Introduction

Opal mining in Ethiopia has surged in prominence following the discovery of substantial opal deposits, particularly within the Wollo Province, encompassing regions such as Wollo and Shewa. Notably, Wegel Tena, situated near the

town of the same name, has emerged as a focal point for opal extraction, yielding exquisite precious opals renowned for their vivid play-of-color, a characteristic highly prized in the gemstone market. An Ethiopian opal is esteemed for their

\*Corresponding author: mamarugenetu81@gmail.com (Mamaru Genetu)

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distinctive qualities, characterized by vibrant hues and intricate patterns. Referred to as "Wollo opals" or "Ethiopian opals" in the gemstone trade, these opals exhibit a diverse spectrum of colors, ranging from fiery reds and oranges to soothing greens, blues, and purples [2, 5, 16, 19, 24].

In Ethiopia, opal mining predominantly relies on small-scale artisanal operations employing traditional techniques like hand tools and rudimentary machinery. However, navigating the rugged terrain and accessing opal-bearing layers pose considerable challenges. Despite these hurdles the Ethiopian government recognizes the industry's economic potential and has initiated efforts to support its growth. Nonetheless, impediments such as infrastructural limitations, inadequate access to financing and technology, and regulatory concerns persist, warranting comprehensive solutions for sustainable development [1, 6, 21].

Overall, Ethiopia's opal mining sector presents promising opportunities for local communities and the global gemstone market alike. With strategic investments and holistic development initiatives, Ethiopia stands poised to assert itself as a significant player in the international opal trade arena (Figure 3). Additionally, the worldwide demand for opals underscores their enduring appeal, with Ethiopian opals, distinguished by their vibrant colors and competitive pricing, capturing increasing attention alongside traditionally esteemed varieties like Australian black opal [2, 11, 22, 23].

The demand for opals is driven by a multitude of factors that intersect within the realms of fashion, culture, investment, and market dynamics. Fashion trends play a significant role, with opals frequently featured in jewelry design. The influence of opals in fashion collections and their adoption by celebrities often triggers spikes in demand. Furthermore, gemstone collectors highly value opals for their unique beauty and rarity, eagerly seeking out exceptional specimens with striking play-of-color or distinctive patterns (Figure 2). Additionally, some individuals perceive opals as investment assets, though their speculative nature, owing to quality variability and market demand fluctuations, distinguishes them from more predictable gemstones. Cultural significance also contributes to demand, with opals symbolizing good luck and prosperity in various cultures, driving interest during auspicious occasions. Overall, the steady allure of opals ensures continued interest, augmented by ongoing discoveries of new deposits and strategic marketing endeavors that enhance their appeal globally [3, 7, 9, 13, 10, 20].

Demand for opals is shaped by a complex interplay of factors, including fashion trends, cultural inclinations, and economic conditions. Opal's historical appreciation for its mesmerizing play-of-color has cemented its status as a sought-after gemstone for jewelry and decorative purposes. Notably, emerging markets like China and India are increasingly embracing opal jewelry, contributing to its growing global demand. However, opal's popularity is not immune to shifts in consumer preferences and marketing strategies within the gemstone industry, which can influence demand

dynamics. Despite these fluctuations, the enduring allure of opals ensures their continued relevance in the gemstone market, bolstered by their timeless beauty and evolving perceptions in various cultural contexts [13, 15].

The mining association, local communities, and governments grapple with several significant challenges in the opal mining industry. One prominent issue is the unpredictability of the opal supply chain due to geological uncertainties and stringent environmental regulations, resulting in supply fluctuations and price volatility. Another pressing concern is the variability in opal quality, making it difficult to differentiate between high and low-quality stones, thus impacting consumer confidence and pricing dynamics [17, 18]. Moreover, there's growing pressure for ethical sourcing practices, driven by worries about labor conditions and environmental sustainability, necessitating greater transparency and accountability within the sector. Additionally, the emergence of synthetic opals poses a threat to the market, offering consistent quality at lower costs, although they are yet to rival natural opals' popularity. Furthermore, the opal market faces stiff competition from other gemstones and luxury goods, potentially affecting demand and pricing. Lastly, regulatory hurdles, especially regarding export and import regulations in opal-mining countries, exert influence on the global opal trade and supply chain, adding another layer of complexity to the industry's operations. Addressing these challenges requires collaborative efforts between stakeholders to ensure the sustainability and growth of the opal mining sector [2, 8, 12, 14, 22].

Improving market education is pivotal to enlightening consumers about the unique attributes of opal and its comparative value alongside other gemstones, potentially igniting heightened demand and appreciation. Additionally, embracing sustainable mining and production practices can fortify the industry's reputation, particularly appealing to ethically conscious consumers. Investing in innovation, such as research and development initiatives to refine mining techniques and elevate opal quality, as well as introducing inventive products like opal-based technologies or sustainable jewelry designs, holds promise in unlocking fresh markets and revenue streams. Collaboration among diverse industry stakeholders, including miners, manufacturers, retailers, and policymakers, is imperative in collectively addressing challenges and fostering the sustainable expansion of the opal market [2, 4, 25]. Despite encountering hurdles, the opal industry harbors opportunities for growth and innovation, achievable through strategic endeavors aimed at aligning with evolving consumer preferences and proactively tackling industry challenges.

The focus of this paper is to outline the significant obstacles encountered in opal mining in Ethiopia, including issues related to prospecting, resource availability, and potential utilization. The results offer valuable insights into strategies for responsible and sustainable mining practices in Ethiopia, highlighting the potential economic benefits for both local

communities and the government as a whole.

#### Study Area

The study area is situated near the town of Wogel Tena in the Wollo Province of northern Ethiopia. Access to this loca-

tion is available via the Addis Ababa to Desi main road, followed by an all-weather road spanning approximately 490 kilometers to reach Wogel Tena (Figure 1).

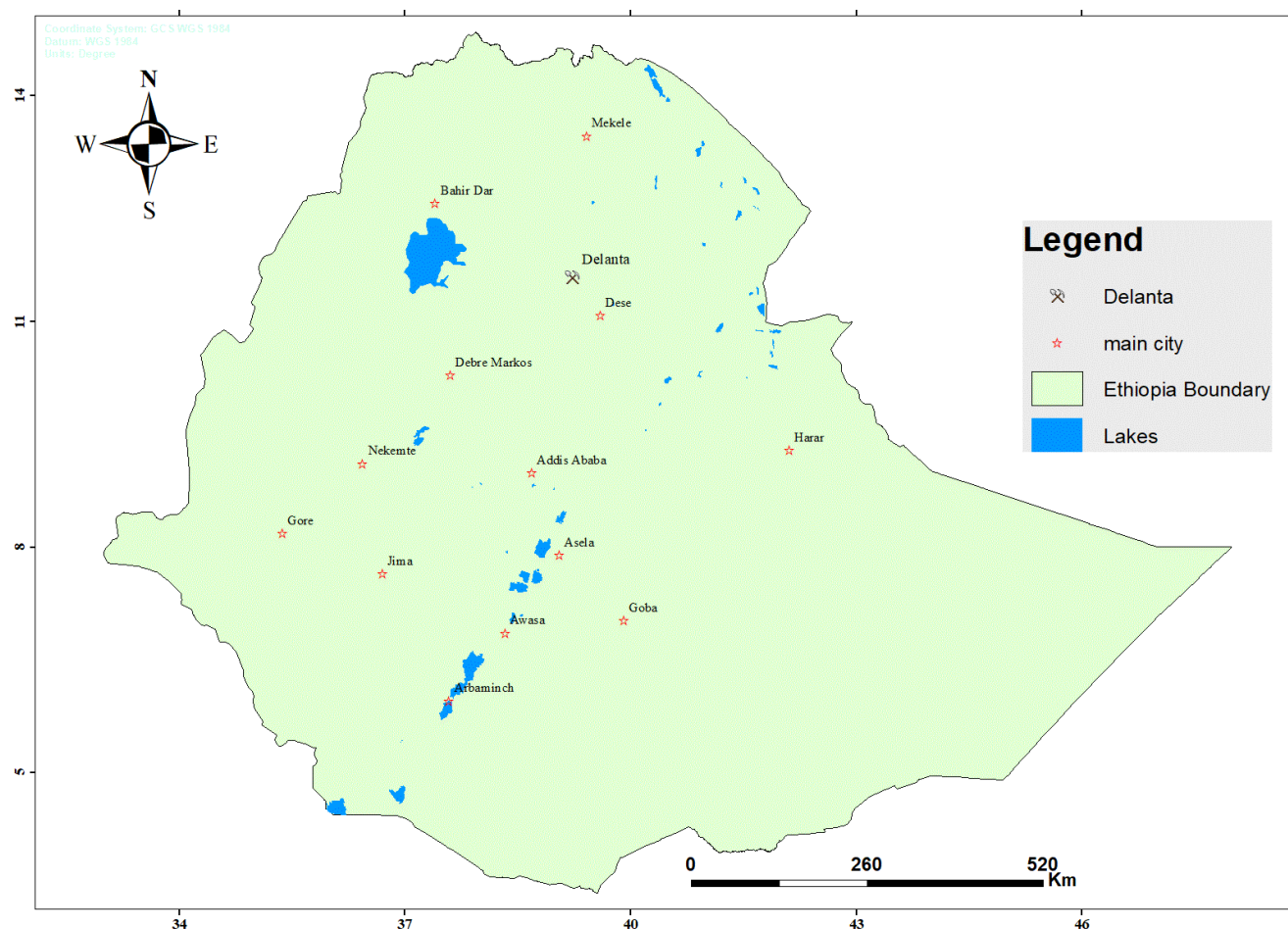


Figure 1. Location map of the study area.

## 2. Methodology

To thoroughly identify and analyze the major challenges faced by opal miners in Ethiopia, a mixed-methods research approach was employed, combining qualitative and quantitative techniques. This approach ensured a holistic understanding of the geological, environmental, and socio-economic factors influencing the gemstone industry. The methodology was designed to capture both the macro-level industry dynamics and the micro-level experiences of stakeholders, including artisanal miners, exporters, and government bodies.

### 2.1. Data Collection Methods

Focus group discussions were conducted with a diverse

group of 25 stakeholders, including representatives from government agencies, gemstone exporters, and artisanal miners. These discussions were structured to encourage open dialogue and gather collective insights into the systemic challenges and opportunities within the gemstone industry. Key topics included regulatory constraints, market access, and operational limitations.

In-depth, semi-structured interviews and questionnaires were administered to a targeted sample of stakeholders, including miners, lapidary unit operators, and industry experts. The questionnaires were designed to explore specific challenges such as access to technology, financial constraints, and the impact of environmental factors on mining operations. The semi-structured format allowed for flexibility, enabling participants to share nuanced perspectives and anecdotal evidence.

Field visits were conducted to observe the operational practices of artisanal miners and lapidary units in Addis Ab-



aba and surrounding mining areas. These visits provided firsthand insights into the working conditions, resource availability, and technological limitations faced by miners. Observations were documented through field notes, photographs, and informal conversations with workers, offering a ground-level perspective on the challenges.

Technical reports from the Ministry of Mines and other relevant government bodies were reviewed to gather statistical data on production volumes, export trends, and value-addition practices. Additionally, secondary data from geological surveys, resource maps, and academic studies were analyzed to contextualize the findings within the broader industry landscape.

## 2.2. Data Analysis

The collected data were analyzed using a combination of qualitative and quantitative techniques to ensure a robust and comprehensive understanding of the challenges faced by opal miners.

Transcripts from focus group discussions and interviews were coded thematically to identify recurring patterns and key issues. These themes were categorized into geological, environmental, socio-economic, and regulatory challenges. The qualitative analysis also incorporated insights from field observations, which provided context and depth to the findings.

Statistical data from technical reports and questionnaires were analyzed using descriptive and inferential statistical methods. This included calculating production trends, identifying gaps in value addition, and assessing the economic impact of mining activities. The quantitative analysis helped validate the qualitative findings and provided a measurable understanding of the industry's challenges.

The primary data from interviews and field observations were cross-referenced with secondary data from technical reports and geological surveys. This integration allowed for a multi-dimensional analysis, highlighting the interplay between geological constraints, environmental factors, and socio-economic barriers. The combined findings provided a comprehensive overview of the industry's current state and identified actionable areas for improvement.

## 3. Result and Discussion

Opal extraction techniques employed in Ethiopia encompass two main approaches: traditional manual excavation and mechanized mining. The traditional method involves small-scale miners utilizing hand tools such as picks and shovels to extract opal-bearing rocks from the ground, followed by manual extraction of opal seams or nodules. In contrast, mechanized mining relies on heavy machinery like excavators and bulldozers to access deeper or larger opal deposits, resulting in increased efficiency and productivity. While traditional hand digging is labor-intensive and suitable for shallow deposits, mechanized mining offers higher

throughput but requires substantial investment in equipment and infrastructure. Both methods necessitate adherence to environmental regulations to ensure sustainable mining practices.

Ethiopia, particularly the Amhara Regional State, recognized as a significant hub for opal gemstone resources. The extraction and exportation begin since 2008 primarily been carried out by artisanal miners [19]. Mining activities are concentrated in localities such as Wollo (Delanta), Northern Shewa and Gondar (Tikil Dingay), renowned for their opal deposits. Additionally, recent mining endeavors in Wollo, specifically in the Delanta area near Wegel Tena and Tsehay Mewcha, have yielded valuable multi-colored rough opals through traditional methods [19, 20].



*Figure 2. Wollo crystal opal.*

The opal in Ethiopia was discovered in 1994 and has since grown to have an impact on the world market. It rivals Australian opal is seen to be more expensive, despite, the Ethiopia's high quality. Despite the promising potential of Delanta's precious opal as a natural resource for economic development and the expansion of the gemstone industry, significant challenges hinder its utilization discussed as follow sections (Figure 3).

### 3.1. Opal Production

In the 2022/23 fiscal year, the sector generated approximately \$2.06 million, and \$0.65 million, through the export of 50.785 kg of rough opal, and 731.12 kg of polished opal, respectively. These figures demonstrate the significant economic contributions made by Ethiopia's gemstone industry. The growth in artisanal mining, the expansion of the exporter base, & the increasing export revenues highlight the sector's

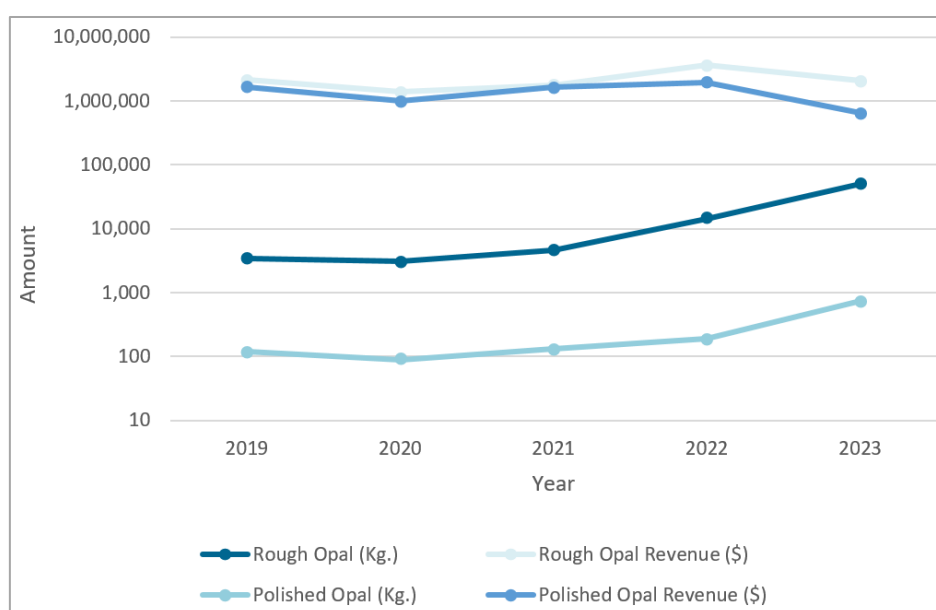
potential to drive economic development and job creation in the country.

**Table 1.** Ethiopian opal export [26].

Type	Description	Unit	2019	2020	2021	2022	2023	Total
Rough Opal	Quantity	Kg	3,472.4	3,057.4	4,694.1	14,368	50,785	76,376.9
Total Revenue generated		M\$	2.14	1.42	1.7786	3.654	2.066	11.0585
Polished Opal	Quantity	Kg	118.7	89.56	130.775	190.97	736.11	1266.177
Total Revenue generated		M \$	1.662	0.993	1.6373	1.9497	0.65	6.8 M\$

However, to fully realize the industry's potential, Ethiopia must continue to invest in skills development, infrastructure, and policies that support the growth of value-addition activities within the gemstone sector. This could include measures to incentivize local processing and manufacturing, improve access to financing, and enhance the competitiveness of

Ethiopian gemstones in the global marketplace. By capitalizing on its abundant gemstone resources and fostering a thriving, value-added gemstone industry, Ethiopia can further strengthen the positive economic impact of this dynamic and growing sector (Figure 3 and Table 1).

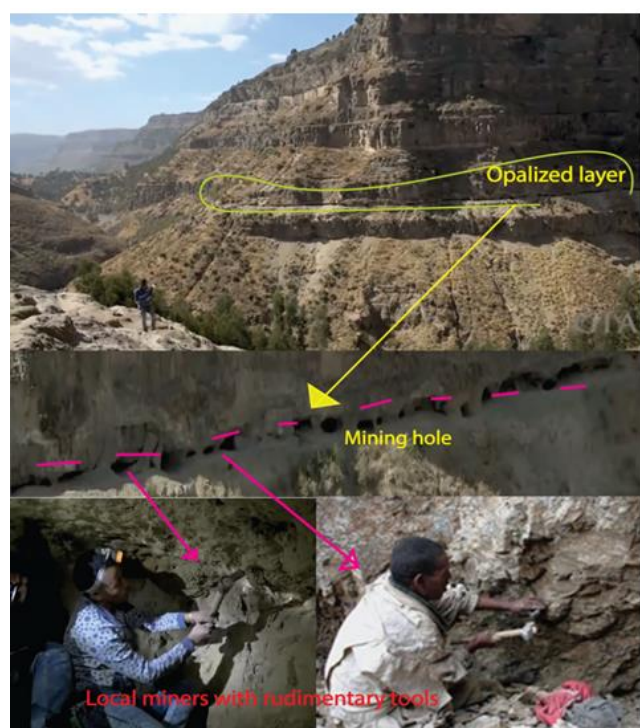


**Figure 3.** Opal production and collected revenue [22, 26].

### 3.2. Artisanal Mining

The prevailing approach among small-scale miners in Ethiopia involves traditional hand digging, which remains the primary method employed. Currently, mining practices lack thorough study, with a notable absence of engagement from large-scale mining companies and insufficient promotional efforts. Operations proceed without detailed planning or machinery utilization, highlighting the industry's rudimentary

nature. In this technique, miners utilize basic hand tools like picks, shovels, and hammers to unearth opal-bearing rocks from the ground. Subsequently, these rocks are meticulously broken down, and the opal seams or nodules are extracted manually. This method is characterized by its labor-intensive nature and relies significantly on the expertise and proficiency of the miners to identify and extract opals efficiently. Typically, it finds application in regions where opal deposits are shallow and can be reached through manual labor (Figure 4).



**Figure 4.** Delanta mine topography, quarry site and hand digging excavation of mining tunnel [25].

Indeed, both traditional hand digging and mechanized mining present distinct advantages and challenges. Traditional hand digging, accessible to small-scale miners, often entails lower initial costs and provides a means for local communities to engage in mining activities. Conversely, mechanized mining offers heightened efficiency and productivity, particularly suited for larger-scale operations capable of extracting significant volumes of opal-bearing material in shorter durations (Figure 4). However, regardless of the method employed, it is imperative to meticulously assess and address the environmental impact, ensuring adherence to regulations and promoting sustainable mining practices. By prioritizing environmental stewardship and regulatory compliance, both traditional and mechanized mining approaches can contribute to responsible resource extraction while safeguarding ecological integrity for future generations.

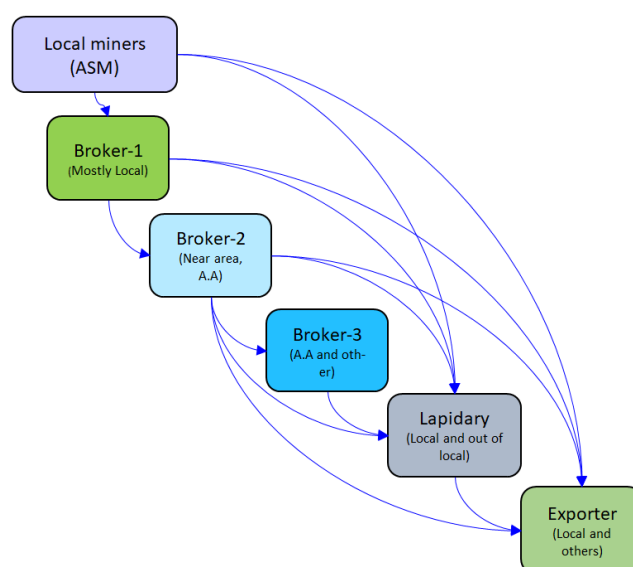
The use of traditional mining tools by miners often leads to cracking issues in opals due to improper handling practices. These cracks pose in the temporary storage of opals in unsafe conditions, exacerbating the problem further. Consequently, many rough opals end up cracked, significantly diminishing their value and forcing miners to sell them at substantially reduced prices. This serious problem not only impacts the opal market adversely but also results in significant economic losses for both the miners and the country as a whole (Figure 4).

### 3.3. Market Chain

The opal marketing system encounters substantial obstacles

in Delanta, as reported by miners from downstream to upstream processes. These difficulties largely stem from the limited commitment of both governmental bodies and private sectors. The primary challenges include the sale of rough opal at unfairly low prices, issues related to smuggling, inadequate promotion of the market, and weak relationships within the market (Figure 4). Lapidaries have expressed frustration over the lack of buyers, with some noting instances where exporters purchase opals at significantly reduced rates. These marketing-related issues contribute to a loss of foreign currency and have adverse effects on the country's economic advancement.

Moreover, the market chain fails to adequately support local miners, given the fluctuating market prices and the presence of illegal traders, commonly known as brokers. Furthermore, governmental efforts to promote the opal industry in international markets fall short of maximizing potential benefits. Key hurdles include retaining produced and polished opals due to high financing needs and lack of bank loans compared to other commodities.



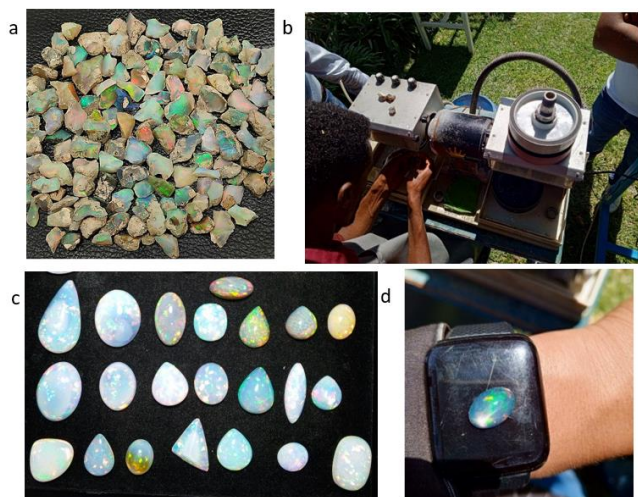
**Figure 5.** Market chain of the opal.

### 3.4. Lapidaries / Value Addition

The primary factors contributing to value addition challenges in the opal industry include the absence of modern lapidary machinery, inadequate lapidary facilities, and a shortage of domestic expertise in jewelry production. Although a few lapidary training centers were established in the Amhara Region in 2009, situated within local Polytechnic Colleges, many of these centers are non-operational, with some even closed down and some found in Addis Ababa (Figure 6b). This situation arises from a lack of qualified trainers possessing the requisite practical experience and skills necessary to effectively train trainees in gemstone cut-



ting and polishing techniques. Promotion value addition within the opal industry and enhancing the skill base in jewelry production, thereby contributing to the industry's growth and development (Figure 6).



**Figure 6.** a, rough opal, b, simple opal lapidary machine c and d polished opal (photos capture in orbit Ethiopia 13/1/2024).

### 3.5. Environmental and Safety Issues

The mining sites in the Delanta district face a range of environmental issues, including deforestation, landslide risks, land degradation, water pollution, downstream sedimentation, and improper disposal of mining waste onto farmland. These challenges pose significant threats to the local ecosystem and surrounding communities. Deforestation disrupts the balance of the natural habitat, while concealed underground channels and holes can pose safety hazards for miners and locals alike. Landslide risks are exacerbated by mining activities, leading to unstable terrain and potential disasters. Land degradation results from the disturbance of soil and vegetation, impacting agricultural productivity and ecosystem health. Water pollution, caused by mining runoff and waste disposal, contaminates local water sources, posing health risks to both humans and wildlife. Downstream sedimentation further disrupts aquatic ecosystems and can harm downstream communities that rely on clean water sources. Improper handling of mining waste, particularly when disposed of onto farmland, degrades soil quality and diminishes agricultural yields, exacerbating food security challenges in the region. Addressing these environmental concerns is paramount to ensure the sustainability of mining activities and the well-being of local communities in the Delanta district.

In Ethiopia, opal mine collapses have been reported, representing a significant hazard to miners and the mining industry. These collapses occur when the structural integrity of the underground excavations is compromised, leading to the sudden failure of the surrounding rock or soil. Opal mine

collapses can result from various factors, including geological instability, inadequate support systems, or the use of improper mining techniques. Such incidents pose grave risks to miners, including injury or fatalities, as well as causing damage to equipment and infrastructure. On 8/1/2024, over 20 miners were reported missing following a mine collapse, with no recoveries made so far (Figure 7). Additionally, numerous other incidents have been documented in connection with this disaster. Mitigating the risk of opal mine collapses requires rigorous safety protocols, proper engineering design, and regular inspections to ensure the safety of workers and the sustainability of opal mining operations in Ethiopia.



**Figure 7.** Delanta opal mining collapse (captured by; Mr. Berihun 2024).

## 4. Conclusion

Understanding the precise location of each opal specimen is crucial for assessing geological influences on quality and stability, and for determining appropriate mining methods and tools. However, minerals or gems deemed of poor quality, subject to physical property changes over time, or extracted through traditional methods are deemed unsuitable for export (Figure 8). To tackle these challenges, this project aims to evaluate opal mineralogy and geochemistry in the Delanta area, address market-related issues, and introduce new technologies to enhance mining practices and empower miners.

In addition to environmental concerns, social problems such as health and safety issues prevail in opal mining areas in Ethiopia, where there is a lack of environmental impact assessments. The disregard for environmental conservation by miners and local stakeholders exacerbates these challenges. Artisanal small-scale opal face difficulties in securing the necessary capital and knowledge to effectively rehabilitate mining sites, leading to the abandonment of pits that pose hazards to both human life and livestock. Furthermore, the absence of rehabilitation efforts impacts species diversity and ecosystem stability in the region, highlighting the urgent need for comprehensive environmental management strategies to

address these multifaceted challenges associated with opal mining in Ethiopia (Figure 8).

Addressing these challenges necessitates concerted efforts from both governmental and private entities to improve reg-

ulatory frameworks, enhance promotional strategies, and foster sustainable practices within the opal mining and market sectors in Ethiopia.

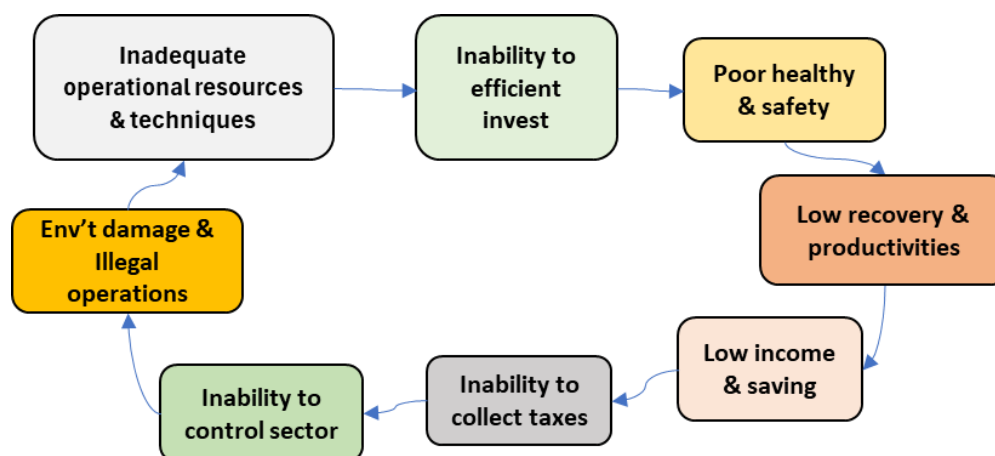


Figure 8. Opal mining cycles of cause and effect.

## 5. Way Forwarded

Stakeholders are encouraged to implement several measures to enhance the opal mining industry in Ethiopia. These include the introduction of low-cost machinery for mining operations and the implementation of site rehabilitation programs to mitigate environmental impacts. Establishing a centralized platform for grading opal at a designated location can streamline the process and foster a free-market system, attracting foreign investment and contributing to the country's economic development. Moreover, improving capacity-building efforts in opal grading and classification, including laboratory analysis of moisture content and mass determination, is essential. Utilizing mobile phones as tools for image acquisition and grading can further enhance efficiency and accuracy in opal assessment. These strategies aim to modernize and optimize the opal mining sector, ensuring sustainable growth and prosperity for all stakeholders involved.

## Abbreviations

ASM	Artisanal Small Scale
MIDI	Mineral Industry Development Institute
MOM	Ministry of Mines

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## Author Contributions

**Mamaru Genetu:** Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft, Writing – review & editing

**Getahun Meseret:** Conceptualization, Formal Analysis, Validation, Visualization, Writing – review & editing

**Gera Techane:** Supervision, Validation, Visualization, Writing – review & editing

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## Data Availability Statement

The data used in the study will be available upon request.

## Conflicts of Interest

The authors declare no conflicts of interest.

## References

- [1] Assamen Ayalew Ejigua, Desalegn Gezahegn Ketemu, Sisay Awoke Endalew and Wudu Yimer Assen, (2020). Challenges in Utilization of Precious Opal in Ethiopia: A Case Study from the Delanta Area, South Wollo, Ethiopia, Abyss. J. Sci. Technol. Vol. 5, No. 2, 14-21, Wollo University, Ethiopia.



- [2] Alemu, M. G. (2018). Artisanal small-scale opal mining (ASOM) insecurity in the Delanta wereda, Ethiopia: The shifting landscape of multidimensional insecurity in the face of emergent ASOM wealth. *African Security Review*, 27(1), 61-87.
- [3] Ayalew, D., & Gibson, S. A. (2009). Head-to-tail transition of the Afar mantle plume: Geochemical evidence from a Miocene bimodal basalt–rhyolite succession in the Ethiopian Large Igneous Province. *Lithos*, 112(3-4), 461-476.
- [4] Bergman, J. (2015). Ethiopian opals: Facts, fears & fairytales. *Gemology*, 393-402, Retrieved from <https://eighthdimensiongems.com/ethiopian-opalsfacts-fears-and-fairytales/>
- [5] Boris Chauviré; Benjamin Rondeau; Francesco Mazzero; Dereje Ayalew, (2017). The Precious Opal Deposit at Wegel Tena, Ethiopia: Formation VIA Successive Pedogenesis Events. *The Canadian Mineralogist* 55 (4): 701–723. <https://doi.org/10.3749/canmin.1700010/>
- [6] Berhane Hailemariam, (2019). Revenues from opal exports have been declining for three years, *Addis fortune*, 20 (994) <https://addisfortune.news/first-opal-trading-center-emerges-in-amhara-state/>
- [7] MoM, Ministry of mines, (2020), Gemstones, Web page accessed on Sep, 18 2024 <http://www.mom.gov.et/index.php/mining/ethiopias-gemstone-potential/>
- [8] Borkena, (2024). Opal mining accident, no miners rescued after four days of search effort, [https://borkena.com/2024/02/12/ethiopia-opal-mining-accident-no-miners-rescued-after-four-days-of-search-effort/#google\\_vignette/](https://borkena.com/2024/02/12/ethiopia-opal-mining-accident-no-miners-rescued-after-four-days-of-search-effort/#google_vignette/)
- [9] Kyngdon-McKay, Y., Jorns, A., Wheat, B., Cushman, T., & Nemomissa, S. (2016). An Analysis of the Commercial Potential of Ethiopia's Coloured Gemstone Industry. *Levin sources*.
- [10] Van der Wal, Sanne and Haan, Esther de, (2010) Rough Cut: Sustainability Issues in the Coloured Gemstone Industry. Available at SSRN: <http://dx.doi.org/10.2139/ssrn.1557705/>
- [11] GSE, (2009). Opportunities for Gem resource development in Ethiopia. Geological survey of Ethiopia, Addis Ababa. Retrieved 1 September 2015. <http://www.gse.gov.et/phocadownload/PromotionDocs/Gemstone%20Potential%20Of%20Ethiopia.pdf/>
- [12] DeMaster, D. J. (2014). 9.4 - the diagenesis of biogenic silica: Chemical transformations occurring in the water column, seabed, and crust. In H. D. Holland & K. K. Turekian (Eds.), *Treatise on geochemistry* (2nd ed.) (pp. 103-111). Oxford: Elsevier.
- [13] Dutkiewicz, A., Landgrebe, T. C., & Rey, P. F. (2015). Origin of silica and fingerprinting of Australian sedimentary opals. *Gondwana Research*, 27(2), 786-795.
- [14] Filin, S., & Puzynin A. I, Alexander. (2009). Prevention of cracking in Ethiopian opal. *The Australian Gemmologist*, 23, 579-582.
- [15] Githiria, J. M., & Onifade, M. (2020). The impact of mining on sustainable practices and the traditional culture of developing countries. *Journal of Environmental Studies and Sciences*, 10, 394-410.
- [16] Johnson, M. L., Kammerling, R. C., DeGhionno, D. G., & Koivula, J. I. (1996). Opal from Shewa Province, Ethiopia. *Gems and Gemology*, 32(2), 112-120.
- [17] Lynne, B., & Campbell, K. (2004). Morphologic and Mineralogic Transitions from Opal-A to Opal-CT in Low-Temperature Siliceous Sinter Diagenesis, Taupo Volcanic Zone, New Zealand. *Journal of Sedimentary Research*, 74, 561-579.
- [18] Milliken, R. E., Swayze, G. A., Arvidson, R. E., Bishop, J. L., Clark, R. N., Ehlmann, B. L., & Weitz, C. (2008). Opaline silica in young deposits on Mars. *Geology*, 36(11), 847-850.
- [19] Rondeau, B., Fritsch, E., Mazzero, F., Gauthier, J.- P., Bekele, E., & Gaillou, E. (2010). Play-of-Color Opal from Wegel Tena, Wollo Province, Ethiopia. *Gems & Gemology*, 46, 90-105.
- [20] Thiry, M., Milnes, A. R., Rayot, V., & Simon Coinçon, R. (2006). Interpretation of palaeo-weathering features and successive silicifications in the Tertiary regolith of inland Australia. *Journal of the Geological Society*, 163(4), 723-728.
- [21] Ayalew, Dereje and Gezahegn Yirgu. (2003). Crustal contribution to the genesis of Ethiopian plateau rhyolitic ignimbrites: basalt and rhyolite geochemical provinciality. *Journal of the Geological Society* 160 (2003): 47-56. <https://doi.org/10.1144/0016-764901-169/>
- [22] Ministry of Mines. 2012. Artisanal Mining Activities in Ethiopia: Challenges and Opportunities. Powerpoint presentation. Retrieved 29 November 2015 [http://www.globaldialogue.info/Artisanal%20Mining%20Activities%20in%20Ethiopia%20-%20Challenges%20and%20Opportunities%20\(Oct%202012\)%20-%20Abayneh%20Tilahun.pdf/](http://www.globaldialogue.info/Artisanal%20Mining%20Activities%20in%20Ethiopia%20-%20Challenges%20and%20Opportunities%20(Oct%202012)%20-%20Abayneh%20Tilahun.pdf/)
- [23] WBG. World Bank Group, (2016), Gemstone Technical Training Manual Ministry of Mines, Petroleum and Natural Gas, Addis Ababa, Ethiopia.
- [24] Tewodros Sintayehu, (2016). Value Addition on Gemstones and its Impact on Ethiopian Economy. Orbit Ethiopia Plc, Power point presentation, Addis Ababa, Ethiopia. Accessed on July, 2024 <https://docslib.org/doc/5055205/value-addition-on-gemstones-and-its-impact-on-ethiopian-economy-by-tewodros-sintayehu-orbit-ethiopia-plc/>
- [25] Eneyew, D. M., Adamu, A. Y., Abebe, S. Z. et al. Economic potentials, challenges and opportunities for sustainable mining in Wollo opal mining, Ethiopia. *Miner Econ* (2024). <https://doi.org/10.1007/s13563-024-00480-9>
- [26] Ministry of Mines. 2024. Annual report of Gemstone, Unpublished report, Addis Ababa, Ethiopia.