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The Mine and Quarry Restoration Network: a new and necessary platform working for the improvement of mine closures

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Abstract

Mining is a strategic sector for economic development, technological advancements and sustaining our current lifestyle by providing essential raw materials. However, mining must rely on best practices to restore environmental impacts to avoid social opposition. This article provides an overview of the mining sector and the development of mine reclamation strategies and techniques in Spain. Spain's geological diversity indicates the existence of a wide variety of deposits, rocks and minerals, which gives rise to a varied and important mining production industry, including critical and strategic raw materials representing approximately 1% of the gross domestic product. Current development of mining in Spain is fully aligned with European Union policies: to boost European industry; to diversify sources for the supply of critical raw materials; and to promote the circular economy. In Spain, mining restoration was not mandatory until the 1980s. Although Spain was relatively late, compared to other Western countries, in incorporating the professional, scientific and technical development of mining restoration, significant progress has been made in recent decades, particularly in research. For years, research related to mining restoration has been on par with international standards. This rapid evolution led to the formation of a multidisciplinary group organised around the Mine and Quarry Restoration Network (MQRN, or Red de Restauración de Minas y Canteras in Spanish), which was established in 2024 as a national non-profit organisation that serves as a pivotal platform for advancing reclamation practices in the mining sector. Comprising key stakeholders – namely mining companies, consultancies, academia and governments – the MQRN fosters collaboration to address the challenges associated with reclaiming mine-disturbed landscapes. Hence the main objective of this

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organisation is to promote efficient and sustainable reclamations that benefit communities and the environment, integrating science, management and previous experiences. Many challenges lie ahead and meeting them will require promoting research and innovation in restoration techniques, supporting companies in the transition to more responsible mining, and strengthening the role of public institutions to lead and integrate these advances in environmental and mining regulations.

Keywords: *Mine and Quarry Restoration Network, mine reclamation, non-profit organisation, standards for mining reclamation*

1 Introduction

Mining is essential for the supply of raw materials and its relevance has arguably increased in the current global geopolitical context. However, mining also has a significant impact on the environment, whose services are also essential to our wellbeing.

In modern society, the extractive industry has a strategic role as a supplier of basic raw materials to the rest of the economy, so any difficulties in the supply of these mining materials can affect the functioning of industrial activity. The development of new technologies, the increasing electrification and digitalisation of the economy and the energy transition process require the supply of minerals (or their chemical elements), which has made some of these raw materials strategic and inevitably leads to an increase in their production (Moratilla-Soria et al. 2023).

Although the global area affected by mining is small (Hooke et al. 2012), its impacts can affect areas beyond the mining sites themselves (offsite impacts). At a local scale, impacts can be alarming (Sigcha et al. 2018). Open cast mining, the most common method of extraction, causes significant alterations in the relief of the landscape by excavating large holes from which vegetation cover, soil, and all associated microbiota and fauna are removed. These processes also alter the web of biotic and abiotic interactions of ecosystems in the surrounding landscape, which have developed over long periods. The modification of the drainage network can increase flood peaks and lead to both physical and chemical contamination of water, affecting the aquifer recharge and subsurface flows. In turn, the machinery emissions generate impacts on local air quality through the release of particles and gases. This negative impact can also affect neighbouring areas, depending on the quality and volumes of emissions, the atmospheric dynamics and the frequency of irrigation on the mine's communication routes, since when these roads are dry the passage of machinery causes fine particles, which the wind can carry over long distances, to rise (Valladares et al. 2017). The loss of ecosystem services is very marked, affecting provisioning services (water, agriculture, livestock, forestry, biodiversity), regulating services (water cycle, carbon cycle) and cultural services (tourism, identity values of the landscape). Briefly, open pit mining leads to a loss of ecosystem services that are equally vital for our survival and quality of life (Nicolau & Moreno de las Heras 2005; Valladares et al. 2017).

On the other hand, the uneven distribution of mining resources which are only found in specific areas has important social implications that need to be considered and integrated into both the mining and restoration phases. Part of society shows great resistance to the opening of new mines while, at the same time, there is an increasingly demanding attitude in society concerning appropriate mine site restoration. The main cause of the strong social opposition to mining is due to the difficulty of making a mining activity compatible with local development projects based on tourism, water quality and landscape values (Valladares et al. 2017). It is crucial to make mining compatible with other resources and values of the territory which the affected communities perceive as essential for their wellbeing.

The importance of mine restoration lies not only in reclaiming landscapes but also in recovering ecosystem functions and degraded services while meeting increasing social demands. The restoration of a mine should always be supported by, and incorporate feedback from, the local community.

In recent decades, more effective restoration concepts and techniques have been developed. However, their application in the mining sector is still not widespread. This limited application is due to a combination of economic, regulatory, technical and cultural factors. For example, high financial costs and a lack of investment are significant barriers; some mining companies are unwilling to commit the necessary resources to implement advanced restoration techniques, prioritising instead short-term profitability. In addition, the absence of strong and enforceable environmental regulation hinders the adoption of more up-to-date restoration practices as, without legal incentives or sanctions, companies may opt for cheaper and less-effective methods.

Technical challenges and ecological complexity also play an important role. Restoration of degraded ecosystems is a complex process that requires a deep understanding of ecological dynamics (Balaguer et al. 2014). This, coupled with limited training on ecological restoration among professionals in the mining sector, results in a general lack of knowledge about restoration practices and their long-term benefits. Another relevant factor is the lack of integration of environmental restoration into the mining lifecycle. Many companies do not consider restoration as an integral part of their operations, which limits proper planning and implementation of effective actions. In addition, without long-term monitoring and evaluation, it is challenging to understand the effectiveness of the restoration techniques implemented, which, in turn, makes it difficult to improve and adjust them for current and future projects. Finally, the lack of interest in corporate responsibility and sustainability also contributes to this situation. Without significant pressure from governments, consumers, investors and society at large, companies may not see restoration as a priority, perpetuating the cycle of under-investment and a lack of effective practices being adopted.

Addressing these challenges requires greater investment in funding, capacity building and consistent operational regulations. Above all, environmental restoration must be integrated into the overall planning and operation of mining projects. In the absence of these structural changes it will be difficult to achieve widespread adoption of advanced restoration techniques that have proven to be effective. In this respect, with the recent adoption of the Regulation on Nature Restoration (European Union [EU] Regulation 2024/1991, EU 2024), the EU has gone a step further in protecting the environment by obliging member states to develop and implement national environmental restoration plans aimed at restoring at least 30% of degraded habitats, such as abandoned mines, by 2030. This new regulatory framework presents an opportunity to improve the integration of environmental restoration into the overall planning and operation of mining projects, at least at the EU level.

2 The mining sector and the evolution of mine restoration in Spain

2.1 The mining sector in Spain

Spain's geological diversity implies the existence of a wide variety of deposits, rocks and minerals, which gives rise to varied and important mining production representing approximately 1% of the gross domestic product This mining wealth places Spain within the EU as the only producer of sepiolite and celestite, the largest producer of fluorspar and gypsum, the second largest producer of copper ore, magnesite and potassium salts, and the sixth largest producer of bentonite. On a global level, Spain stands out as the world's leading producer of slate, the second largest producer of ornamental rocks and marble, and the fourth largest producer of granite (MITECO 2024). This makes Spain a producer of critical and strategic raw materials in the EU (Moratilla-Soria et al. 2023).

National mining production in 2023 (latest data available, MITECO 2024) exceeded EUR 3.571 million, 9.3% less than in 2022. Analysing the data by subsector:

- Quarry products accounted for 34% of the total national production, with an upward trend. Limestone is the main product, both in terms of production volume and total value.
- Metal mining contributed 27%, making it the driving force behind the growth of Spanish mining. In detail, the production of copper has been reduced compared to 2022, while zinc mining has increased in tonnage, although the fall in the price of this metal has led to a reduction in its economic results. On the other hand, national production of tungsten has increased by 28% and iron ore is recovering. Finally, the troy ounce of gold is reaching historic prices year after year.

- Industrial minerals accounted for 25% of the total production.
- Ornamental rocks accounted for 13%, although a downward trend is expected in the long-term due to increased international competition and the replacement of natural stone with synthetic materials. Notable examples of Spain's rocks include slate, which is internationally recognised for its quality, as well as granite and ornamental limestone.
- Energy products accounted for 0.34%, having fallen by 62% compared to 2022. This decline is attributed to a reduction in production and lower prices.

Spain has mines for some critical raw materials: copper, fluorite (fluorine feldspar), feldspar, strontium, lithium, tungsten (essential for the aerospace and defence sectors) and tantalum. The EU has prioritised seven mining projects in Spain for the extraction of critical raw materials, seeking to reduce dependence on other countries. These projects are located in various regions of Spain, including:

- Doade Mine in Ourense, Galicia (lithium)
- Las Navas Project in Cáceres, Extremadura (minerals for batteries)
- El Moto Project in Ciudad Real (tungsten)
- P6 Metals Project in Cáceres, Extremadura (minerals for batteries)
- Aguablanca Project in Badajoz, Extremadura (minerals for batteries)
- Polymetallurgical Refinery Project in Seville, Andalusia (complex mineral extraction processes and the circular economy).

Coal mining has been almost entirely shut down and mercury mining is prohibited. There are uranium deposits, but they are not being mined. There are some projects for the mining of rare-earth elements, but they are not progressing due to social opposition in the areas where the deposits are located.

The development of mining in Spain is fully aligned with European policies, which currently have three main objectives: to boost EU industry, with mining projects forming part of a broader plan to increase European autonomy; to diversify sources for the supply of critical raw materials, especially for the transition to renewable energies and the automotive industry; and to promote the circular economy. This is facilitating access to financing and simplifying the procedures for these projects. Furthermore, the demand for certain metals that are key to the ecological and digital transition and the application of circular economy criteria, as well as new technologies in mining, is leading to greater use of materials that were previously discarded and accumulated in waste dumps and tailings. This reduces the need for raw materials and the volume of waste from mining, which also affects the recovery of mining areas.

As in other countries, mining activity in Spain is mainly carried out in open pits, while underground mining has remained very limited. The area occupied by mining in Spain has increased significantly in recent decades, despite a decrease in the number of mines. Between 1987 and 2005 it went from 46,063 ha (0.091% of the national territory) to 75,575 ha (0.149%), while the area occupied by spoil tips and landfills remained virtually unchanged (0.012%), falling from 6,098 ha to 5,914 ha (Prieto et al. 2014).

2.2 The evolution of mine restoration in Spain

In Spain, mining restoration work was not mandatory until the implementation of the Royal Decree 2994/1982 on 15 October (Real Decreto 2994/1982, de 15 de Octubre). This mandatory state regulation required the development of a Natural Area Restoration Plan (Plan de Restauración del Espacio Natural in Spanish). This plan had to describe the actions that would be carried out in relation to the conditioning of the land surface, and measures to prevent possible erosion and protect the landscape, among others. Thus, the development of knowledge and techniques for the practice of mining restoration began in Spain in the 1980s.

Over the last few decades there has been a substantial transformation in restoration strategies in mining areas, mainly due to a significant change in the understanding and perception of ecological impact and the focus on recovery of ecosystems degraded during mining activity. Here is a summary of the main aspects observed in Spain, which are also conditioned by the evolution of regulations in this country – although, broadly speaking, they can be extrapolated to other regions of the world.

2.2.1 1980s and 1990s

In the 1980s and 1990s the main focus of mine restoration was on mitigating the visual impact of mining activities, as well as controlling run-off and managing sedimentation through rigid structures, usually concrete, equivalent to those used in civil engineering. This predominantly agronomic approach involved practices such as the use of fills to cover mining faces, commercial herbaceous plantings, and monospecific tree plantations of species resistant to drought and other shortcomings (e.g. soil pH, salinity) (Martínez-Ruiz et al. 2007; González-Alday et al. 2008; Alday et al. 2011; Milder et al. 2013; Torroba et al. 2015; López-Marcos et al. 2020). A simple design model was used based on a slope-ditch-berm configuration derived from the shapes adopted during mining works plus rigid structures to convey water and sediment to ponds (see Nicolau 2003). This model focuses more on the physical stability of the land than on the recovery of ecological functionality. Although it requires continuous maintenance, this approach has been used in several mining sectors (open cast mining) due to its simplicity and because it is easily adaptable to the shapes resulting from mining works.

2.2.2 First decade of the 21st century: 2000 to 2010

Between 2000 and 2010 a transformation of the sector towards a more ecological approach began to take place, based on geomorphological principles that seek to minimise erosion and create functional, self-sustainable spaces that are better integrated with the environment (Martín Duque et al. 2010). At this stage, techniques were developed and implemented to improve the quality of the substrate for vegetation. They are typically made from inert waste and organic matter. Revegetation efforts increasingly focused on the formation of diverse plant communities, recognising the importance of biodiversity in restoring ecosystem services (Alday et al. 2011). This approach was a breakthrough in ecological restoration as it aimed not only to cover the soil but also to restore the functionality of the ecosystem and improve its capacity to support life.

2.2.3 From 2010 to the present day

In recent years there has been an even more significant advance in the integration of ecological and geomorphological knowledge of restoration (Martín Duque et al. 2014, 2015, 2019; López-Marcos et al. 2020; Martínez-Ruiz et al. 2021a, 2021b). An ecological approach that prioritises the creation of biologically functional soils has gained prominence, implying a better understanding of the interactions between soil organisms and plants (Adamo et al. 2022; Muñoz-Cerro et al. 2024). There have also been advances in revegetation, integrating greater species diversity and prioritising the use of native species. This approach is not only based on the use of advanced technologies in geomorphological restoration but also on greater scientific transfer between researchers and professionals in the sector. Public-private partnerships have enabled the implementation of more ambitious and effective projects, thereby driving innovation in restoration practices. In addition, over the last several years, the concept of progressive reclamation has started to be integrated into the planning of mining activities. This means that restoration practices are not only considered at the end of the mine life but are also implemented continuously throughout the project lifecycle. This integration of mining and restoration allows for a more dynamic adaptation to changing ecosystem conditions and a more effective recovery of ecosystem services.

These changes in the application and perception of mine restoration are not only relevant from a scientific point of view but also respond to increasing social and regulatory demands for sustainability and the environmental responsibility of operators. This evolution of ecological restoration techniques and objectives reflects a growing recognition of the importance of biodiversity and ecosystem functionality, as well as the need to mitigate the negative impacts of mining. In short, the development of ecological restoration in mining has shifted from a purely pragmatic approach – focused exclusively on meeting legal requirements with little integration into the activity itself – to one that seeks a true balance between mining activity and ecosystem conservation, thus paving a path towards more sustainable and responsible mining.

Although mining restoration began late in Spain (in the 1980s), and essentially starting from scratch, extraordinary progress has been made in recent decades. In fact, it can be said that Spain has surpassed many EU countries in specific aspects of mining restoration, such as land remodelling.

Two conclusions can be drawn from this section: (a) Spain was very late, compared to other Western countries, in incorporating the professionalised, scientifically and technically based development of mining restoration; and (b) in recent decades, significant progress has been made, especially in research – and research related to mining restoration has matched international research standards for years.

3 The creation of the Mine and Quarry Restoration Network

The Mine and Quarry Restoration Network (Red de Restauración de Minas y Canteras – RedRMYC in Spanish) emerged in Spain within this context of advances in mining restoration, mainly developed and promoted through significant projects formed by consortiums including companies, government bodies, research centres, universities and technical specialists such as:

- LIFE TECMINE (https://mediambient.gva.es/es/web/life-tecmine/inicio)
- LIFE RIBERMINE (https://liferibermine.com/en/homepage_en/, Martín Duque et al. 2022, 2024)
- RESTOQUARRY (Carabassa et al. 2019)
- RESTARC (https://www.creaf.cat/research-innovation-and-promotion-use-amendments-andorganic-residues-soil-restoration)
- RESTORMINE (https://www.linkedin.com/in/restormine-research-group-2291312b4/, https://portaldelaciencia.uva.es/proyectos/629865/detalle)
- LIFE ECORESTCLAY (https://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/empresa_i_produccio_sostenible/restauracio_dactivitats_extractives/Programes-o-plans-de-restauracio/exemples_dactuacions/triptico-cantera-cemex-02.pdf)
- LIFE CARBON2MINE (http://www.carbon2mine.es).

3.1 Mine and Quarry Restoration Network objectives and motivation

The MQRN (RedRMYC) was created to promote collaboration among companies, administrations and academics in mining restoration (Figure 1). Its main motivation arises from the growing need to share the scientific and technical knowledge of professionals across Spain.

The main objective of this non-profit association is to promote and advance mine restoration, integrating the experience of the scientific community, public administration, mining companies, and engineering and consultancy firms throughout Spain, and developing standards that are technically feasible, economically sustainable, and environmentally and socially acceptable.

Mine and quarry restoration must be an efficient and sustainable process that benefits both communities and the environment.

Figure 1 The four pillars of the Mine and Quarry Restoration Network: mining companies, engineering and consultancy firms, the scientific community and public administration

3.2 Mine and Quarry Restoration Network lines of work

The lines of work of the MQRN serve the needs of the members and are always aligned with the association's objectives. Several areas are already being developed:

- organisation of training courses, seminars, webinars and theoretical-practical sessions
- advice to companies and administrations on various aspects of mine restoration
- development of a collaborative platform for knowledge and experience transfer to share needs and solutions, and identification of technical-scientific needs
- promotion and participation in research and development projects, as well as in seminars, conferences and specialised journals, giving visibility to best practices in mine restoration.

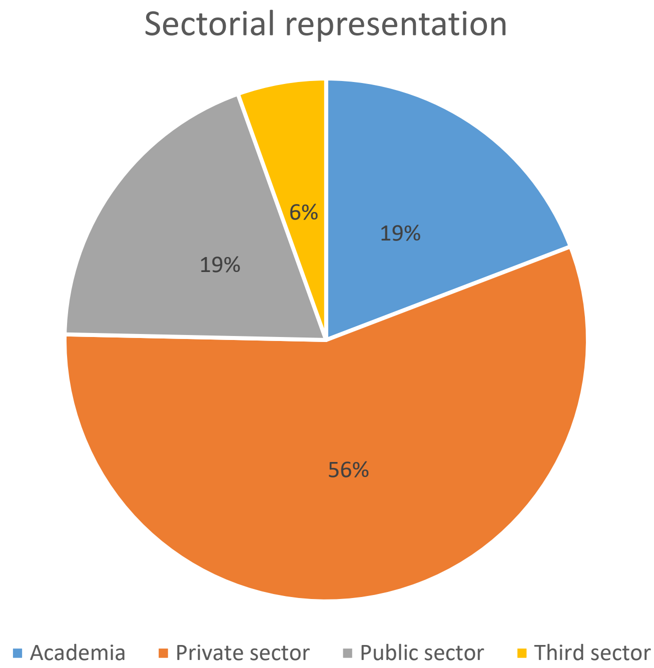
Finally, thanks to the collaboration with the European Climate, Infrastructure and Environment Executive Agency, work is underway to develop initiatives aimed at defining standards for mine reclamation implement certification and environmental labelling systems, and to organise an international conference (Figure 2).

Figure 2 The lines of work of the Mine and Quarry Restoration Network

3.3 Who we are

The MQRN is composed of individual and institutional partners representing academia (researchers), the private (companies) and public (administrations) sectors, and non-government organisations/foundations /associations (Figure 3). Research groups in Spain include professionals from different and complementary fields such as geology, geochemistry, soil science, forestry, ecology, geomorphology, biodiversity, mining, geotechnics, botany, landscape and wildlife. These specialists belong to different universities and research centres: Complutense University of Madrid, Rey Juan Carlos University, Polytechnic Universities of Cartagena, Madrid and Valencia, Universities of Zaragoza, Valladolid, Alcalá, Alicante, Oviedo, Huelva, Lisboa, and Lleida Instituto de Recursos Naturales y Ordenación del Territorio – Institute of Natural Resources and Land Management, Centro de Investigación Ecológica y Aplicaciones Forestales – Centre for Ecological Research and Forestry Applications, Centro de Estudios Ambientales del Mediterráneo – Centre for Mediterranean Environmental Studies and Centro Tecnológico del Mármol (Marble Technological Centre).

The private sector includes national and multinational mining companies and consultancy firms. It also includes the leading group in Europe in geomorphic restoration, which made it possible to recognise such techniques as one of the Best Available Techniques for the Management of Waste from Extractive Industries in the EU by the European Commission (Garbarino et al. 2018).



(a)

(b)

Figure 3 Members of the Mine and Quarry Restoration Network: (a) By sector; (b) Institutional partners

4 Future challenges

The MQRN's journey has only just begun and there are many challenges ahead, not only for this association but for the entire mining sector. From our perspective, the solution to these challenges will always be anchored in the principles of the association and based on collaboration between partners.

Whether at the national, European or international level, the network will continue to promote sustainability in the mining sector as we are convinced that this is the way forward for the sector. Mining restoration projects should focus on recovering functional ecosystems in the short and long-term. This involves using reference ecosystems based on local native species composition, but also considering cultural values and adaptive approaches that incorporate the potential implications of climate change to ensure that the restored ecosystems are self-sufficient in the long-term.

Innovation is another key pillar. The integration of nature-based solutions, such as geomorphological restoration, the creation of "technosoils" and the promotion of positive interactions present opportunities for more efficient restoration, both ecologically and economically.

It is also essential to promote progressive restoration, understood as an inseparable part of the mining process, involving integrating the restoration of areas affected by the extractive activity throughout the life of the mine, rather than waiting for mine closure. This approach reduces the cumulative environmental impact and improves social acceptance.

The circular economy is also an opportunity for the future as integrating circular economy principles into mining waste management could transform environmental liabilities into assets by recycling and reusing mining materials for new industrial uses.

Monitoring programs will allow the collection of information on novel and successful restorations and assist in the development of techniques with proven results. New tools, such as remote sensing, drones, artificial intelligence and big data analyses, can improve the assessment and monitoring of restored areas, optimise efficiency, reduce costs and have other applications in different sectors of mining development. In this sense, the establishment of standardised indicators to measure restoration success will help to improve practices and make them replicable across different projects and regions. Future projects should incorporate scientific knowledge gained from monitoring both successful and unsuccessful restoration efforts into their design and planning to ensure lessons are learned and applied effectively. Linked to this, a policy of certification and audits through external evaluation systems can strengthen credibility and ensure that restoration commitments are efficiently implemented.

On the other hand, integrating restoration into the regulatory framework and adapting it to contemporary challenges remains one of the biggest obstacles. It is necessary to coordinate mine restoration plans with international commitments, as well as with national and regional regulations.

Another aspect that needs to be considered and worked on in the future is the cost and financing of restoration. Mine restoration involves high costs. As such, it is crucial to ensure adequate funding. One of the main difficulties is ensuring that financial guarantees are available and sufficient to cover the costs of quality restoration.

Recently it has become clear that community participation is of paramount importance. Increasingly evident is the need to involve local communities in restoration processes to ensure that projects reflect social needs and expectations. This also contributes to legitimacy and long-term success.

As is evident here, there is no shortage of challenges for the mining sector to address in the future, and the MQRN can play a decisive role in this regard.

5 Conclusion

Mining is an essential activity for the supply of raw materials and is fundamental for industrial and technological development. However, its environmental impact is significant, affecting key ecosystem services such as the regulation of water and carbon cycles, the provision of water, soil and biodiversity, and the quality of the landscape. It is not a question of choosing between mining and nature but of finding a balance that allows the sector to develop sustainably.

The impact of mining is not only the responsibility of the mining industry but also of the consumers who use the extracted resources.

In recent years, Spain and other countries have taken important steps to restore mining sites. Innovative projects have developed advanced concepts and techniques that go beyond mere aesthetic compensation and are committed to triggering ecological processes that restore key ecosystem functions. This new perspective not only enhances biodiversity and contributes to international conservation commitments but also generates value for areas where mining is carried out.

We are facing a paradigm shift that requires time, commitment and collaboration. Science has once again shown that viable solutions exist to advance sustainability. Now is the time for the mining sector and public administration to embrace this knowledge transfer and integrate it effectively into project planning and implementation.

To achieve this, it is essential to: (a) continue to promote research and innovation in restoration techniques; (b) support companies in the transition to more responsible mining; and (c) strengthen the role of public institutions to lead and integrate these advances in environmental and mining regulations.

With the MQRN we have worked to connect, promote and consolidate advances in mine restoration at the state level in Spain. With the support of the European Commission, we aim to develop mine restoration standards that serve as an effective tool to evaluate and improve projects not only in Spain but also at the European and even international levels, which are important challenges for the future.

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