McMaster University | Health Forum

Rapid evidence profile

Examining the evidence landscape for the socio-economic and environmental effects of deep-sea mining

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Context

- The rapidly growing demand for specific metals and minerals combined with challenges with the terrestrial mining industry is spurring industry stakeholder and governments to look to the ocean floor for an alternative.
- The primary focus of deep-sea mining is on three types of deposits, namely, polymetallic nodules, sulphides from active and inactive hydrothermal vents, and cobalt-rich ferromanganese crusts.
- However, the deep sea remains one of the most unexplored environments on earth and we know very little about its biogeochemical make-up or the ecosystems that it supports.
- In areas beyond national jurisdictions, extraction of mineral resources at the seafloor is managed by the International Seabed Authority (ISA), an organization established by the United Nations Convention on the Law of the Sea (UNCLOS) to organize, regulate, and control seabed mining on behalf of humankind.
- In accordance with the declaration, the ISA must, among other things, prevent 'serious harm' and ensure the 'effective protection of the marine environment' from harmful effects, which may occur from deep-sea mining activities.
- This rapid evidence profile examines at a high-level what is known about and where there remain significant research gaps related to the effects of deep-sea mining and relies on what has been included in evidence syntheses that meet minimum methodological criteria.
- This rapid evidence profile has been prepared by a team with methods expertise in conducting rapid evidence reviews, however with no subject matter expertise in deep-sea mining or other related fields, though the framework used for data extraction was sent to a subject matter experts for feedback.

Box 1: Evidence and other types of information

+ Global evidence drawn upon

Evidence syntheses selected based on relevance, quality, and recency of search

- No forms of domestic evidence used

- No other types of information used

*** Additional notable features**

Prepared in three-business days using an 'all hands-on deck' approach

Question

1) What do we know about the benefits and harms of deep-sea mining?

High-level summary of key findings

- We identified 12 highly relevant evidence synthesis that informed the question, all of which note significant gaps in the research evidence available to inform decisions regarding deep-sea mining.
- Some of the included evidence syntheses point to challenges in the literature, namely that it tends to emerge from the global north and has few mentions of how the noted implications differ for coastal communities or Indigenous peoples.
- One evidence synthesis that mapped the available literature on environmental baselines and impacts from deep-sea mining notes two areas where there is sufficient research to inform evidence-based decision-making, namely the baseline knowledge regarding polymetallic nodules in the Clarion Clipperton Zone and the direct environmental implications of removing polymetallic nodules from the sea floor.
- However, another evidence synthesis noted the following key gaps in the understanding of the field:
    - the environmental baselines of much of the deep sea including the abiotic and biotic factors of habitats and how these vary within and between ocean basins
    - the magnitude, spatial and temporal extent of deep-sea mining impacts on the environment and how these vary within and between ocean basins
    - ecological tipping points and timescales for recovery
    - the effectiveness of existing or proposed management and mitigation efforts (i.e, Areas of Particular Environmental Interest in the Clarion Clipperton Zone)
    - global mineral demand projects and the mix of supply (e.g., terrestrial mining, recycling secondary materials)
    - the economics of deep-sea mining and how profits would be distributed between the global north and global south.
- As the International Seabed Authority has granted 22 exploration contracts, these gaps have critical implications for considering the development of management and mitigation efforts of existing contracts, as well as governance mechanisms including the use of the precautionary principle and setting of environmental and scientific thresholds.
- High-quality living evidence synthesis could be helpful to support the establishment of a more structured research agenda to begin filling identified gaps in the evidence base.

Box 2: Approach and supporting materials

At the beginning of each rapid evidence profile and throughout its development, we engage a subject matter expert who help us to scope the question and ensure relevant context is taken into account in the summary of the evidence.

We identified evidence addressing the question by searching Social Systems Evidence, Scopus and Web of Science. All searches were conducted 28 November 2024. The search strategies used are included in Appendix 1. In contrast to synthesis methods that provide an in-depth understanding of the evidence, this profile focuses on providing an overview and key insights from relevant documents.

We searched for full evidence syntheses (or synthesis-derived products such as overviews of evidence syntheses) and intend to complement this work in the coming month with additional insights from recently published single studies.

We appraised the methodological quality of evidence syntheses that were deemed to be highly relevant using the first version of the AMSTAR tool. AMSTAR rates overall quality on a scale of 0 to 11, where 11/11 represents a review of the highest quality, medium-quality evidence syntheses are those with scores between four and seven, and low-quality evidence syntheses are those with scores less than four. The AMSTAR tool was developed to assess reviews focused on clinical interventions, so not all criteria apply to evidence syntheses pertaining to delivery, financial or governance arrangements within health systems or implementation strategies.

A separate appendix document includes:

- methodological details (Appendix 1)
- details about each identified synthesis (Appendix 2).

This rapid evidence profile was prepared in the equivalent of three days of a ‘full-court press’ by all involved staff.

Framework to organize what we looked for

- Metal-rich mineral deposits
  - Polymetallic nodules
  - Polymetallic sulphides
    - Active
    - Inactive
  - Cobalt-rich ferromanganese crusts
- Environmental baselines
- Environmental consequences on fauna, biodiversity, ecosystems and ecosystem services both overall and by mineral and approach to mining
  - Direct and indirect impacts of mining in sea-bed ecosystems
    - Removal of resources
    - Plumes
    - Contaminant release and toxicity
    - Noise, vibration and light
  - Direct and indirect impacts from processing sea-bed minerals
  - Management and mitigation measures for environmental impacts
  - Timescales and recovery times
- Human health consequences, both overall and by mineral and approach to mining
  - Direct and indirect impacts of mining in sea-bed ecosystems or processing minerals
  - Management and mitigation measures
- Public opinion and societal considerations
  - Public attitudes
  - Industry opinion
- Economic considerations
  - Demand for minerals coming from deep-sea mining
  - Supply of minerals coming from deep-sea mining
  - Economic implications for communities involved or affected by deep-sea mining or mineral processing
- Equity considerations
  - Coastal communities
  - Indigenous communities
- Governance mechanisms for deep sea mining
  - International regulations (e.g., Convention on the Law of the Sea)
  - Experimental/exploratory licenses
  - Precautionary approach/principle
    - Setting environmental and scientific thresholds
  - Risk-risk framing
    - Taxonomy of harm

What we found

We identified 12 evidence syntheses, all of which were determined to be highly relevant to the question. However, we assessed many of these evidence syntheses as being of low and medium methodological quality as they lack high-quality transparent methods that detail how single studies were chosen for inclusion and/or how findings from included studies were combined.

Coverage by and gaps in existing evidence syntheses and domestic evidence

In general, evidence syntheses related to deep-sea mining note considerable gaps in the evidence base across all the domains of the organizing framework. One recent high-quality evidence synthesis describes that with respect to environmental baseline and impacts, only two areas have significant amounts of reliable research to inform evidence-based decision-making.(1) Notably, there is a relatively good baseline understanding of active sulphides, as well as polymetallic nodules specifically in the Clarion Clipperton zone including both biotic and abiotic factors of both habitats. In addition, there is a relatively strong understanding of the direct environmental impacts of removing polymetallic nodules from the seafloor.(1)

According to one recent low-quality evidence synthesis conducted for the Government of the United Kingdom in 2021, key areas of uncertainty related to deep sea mining, include:

- the environmental baselines of much of the deep sea including the abiotic and biotic factors of habitats and how these vary within and between ocean basins
- the magnitude, spatial and temporal extent of deep-sea mining impacts on the environment and how these vary within and between ocean basins
- ecological tipping points and timescales for recovery
- the effectiveness of existing or proposed management and mitigation efforts (i.e., Areas of Particular Environmental Interest in the Clarion Clipperton Zone)
- global mineral demand projects and the mix of supply (e.g., terrestrial mining, recycling secondary materials)
- the economics of deep-sea mining and how profits would be distributed between the global north and global south.

However, 22 exploration contracts (each lasting 15 years) have been granted by the International Seabed Authority (see Table 1) resulting in increased knowledge and interest in deep-sea mining and in mapping the sea floor. This attention and activity mean that there could be rapid changes over the coming years to this list of known gaps and the emergence of a more structured research agenda.

Table 1: Current sponsoring states and contractors with contracts with the International Seabed Authority for exploration of deep-sea mining (adapted from (2))

Sponsoring state	Type of contractor	Number of polymetallic nodule exploration contracts	Number of polymetallic sulphide exploration contracts	Number of ferromanganese crusts exploration contracts
Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia	Governmental body	1		
Russian Federation	Private entity; governmental body	1	1	1
Republic of Korea	Member state	1	1	1
China	Governmental body; State-owned company	3	1	3
Japan	Private entity; governmental body	1	2	1
France	Research organization	1	1	
India	Member state	1	1	

Sponsoring state	Type of contractor	Number of polymetallic nodule exploration contracts	Number of polymetallic sulphide exploration contracts	Number of ferromanganese crusts exploration contracts
Germany	Research organization	1	1	
Nauru	Private entity	1		
Tonga	Private entity	1		
Belgium	Private entity	1		
United Kingdom	Private entity	2		
Kiribati	Private entity	1		
Singapore	Private entity	1		
Cook Islands	Private entity	1		
Republic of Poland	Member state		1	
Brazil	Governmental body			1
Jamaica	Private entity	1		

While most of the included evidence syntheses speak to what we know (or don't know) about the deep sea or the impacts of proposed deep-sea mining, two examined the narratives present in studies about deep-sea mining. These are important to bear in mind when considering what perspectives may be dominant in the evidence base. One recent low-quality evidence synthesis (pre-print) found that the majority of the literature on deep-sea mining includes a growthism perspective (e.g., where the eventual economic need for deep-sea mining is assumed) and is predominantly published in the global North, largely from Europe and the U.S.(3) A second recent medium-quality evidence synthesis described four narratives present in the literature:

- a green economy in a blue world - which views deep sea mining as a potential solution for meeting mineral demands for green technologies and argues that it could have fewer environmental and social impacts than land-based mining
- sharing of deep-sea mining profits – which focuses on the equitable distribution of deep-sea resources and highlights the tension between the global north and global south
- depths of the unknown – which emphasizes the scientific uncertainties about deep-sea ecosystems and calls for more research before proceeding with mining
- let the mineral be - which argues for leaving deep-sea minerals alone and questions the right to exploit these ecosystems, including criticising the International Seabed Authority's governance structure and bias towards exploitation.(4)

The evidence synthesis notes that the first narrative dominates most of the evidence base. (4)

Key findings from included evidence documents

In the section below, we profile what is known from the 11 identified evidence syntheses by area of the organizing framework listed above.

Environmental baselines (e.g., understanding of abiotic and biotic factors of habitats)

Two recent evidence syntheses (one high-quality and one low-quality) identified what is known and where there are particular gaps for environmental baselines of each habitat.(1)

For polymetallic nodules, the evidence syntheses found some understanding of the abiotic and biotic factors of habitats is known from the Clarion Clipperton zone as well as from the Central Indian Ocean Basins and West Pacific Ocean.(1; 2) One recent low-quality evidence synthesis states that there are approximately 70 papers describing the baseline conditions of polymetallic nodules from the Clarion Clipperton zone.(2) However, a second synthesis notes that all nodule regions require further sampling to gather enough baseline information for evidence-based management.(1) The variability of nodules is also described in a second recent medium-quality evidence synthesis.(4)

In particular, the included syntheses note that samples from the Clarion-Clipperton zone show variable conditions, nodule size, density and nutrient flux, which may impact assumptions used to inform proxies for management and resilience studies as well as assumptions about environmental impacts.(1) With respect to understanding the taxonomy and ecology, approximately 70-90% of the species collected from these habitats are new to science and estimates predict approximately 25-75% of total species remain to be collected.(1) This information is derived from the Clarion Clipperton zone and indicates that it may be one of the most biodiverse habitats on Earth, however relatively little is known for other polymetallic nodule rich areas.(1) Fauna present in polymetallic nodules in the Clarion Clipperton zone include:

- megafauna such as xenophyophores, cnidarians and sponges as well as larger crustaceans
- macro fauna such as polychaete worms, tanaid and isopod crustaceans
- meiofauna such as nematodes, hapacticoid copepods and foraminifera
- microbiota that lives throughout the water
- nodule biota
- demersal fishes and scavengers in lower density.(2)

Relatively little is known about the ecological connectivity of polymetallic nodules and their ability to withstand local extinctions from disturbances. With respect to ecosystem services, polymetallic nodules are known to provide a non-renewable source of minerals and a habitat to deep-sea biodiversity. In particular, the fauna in nodule regions play a role in carbon fixation, cycling and storage and contribute to nutrient regeneration as well as being an important source of food for select mid-water fauna.(1; 2)

For hydrothermally active polymetallic sulphides, one recent high-quality evidence synthesis describes that a considerable amount is known with respect to both abiotic and biotic factors, with the mid-Atlantic ridge receiving the most scientific attention.(1) In addition, one recent medium-quality evidence synthesis describes the characteristics of active sulphide vents in the Indian Ocean.(5) The synthesis describes that active hydrothermal vents exhibit both dominant species types in abundance due to the harsh and fluctuating environment as well as species rarity (comprising less than 5% of identified species).(5) In addition, one recent high-quality evidence synthesis describes that approximately 70% of mega- and macro-faunal species living in active polymetallic sulphides as being endemic to these habitats (e.g., can only be found in and around the hydrothermal vents).(1) The synthesis describes a high level of variability between hydrothermal vent habitats both between ocean basins but also within basins and the one recent medium-quality evidence synthesis describes the wide range of fauna that have been found across the 13 identified vents in the Indian Ocean.(1; 5) With respect to ecosystem services, the recent high-quality evidence synthesis notes that active vents provide a needed source of minerals but also provide shelter, provisioning services (e.g., pharmaceuticals and biomaterials) and regulating services (e.g., carbon cycling).(1)

For hydrothermally inactive and extinct vents, one recent high-quality evidence synthesis notes that there have been few published studies characterizing this habitat despite it being the most likely to be mined.(1) However, the synthesis describes that inactive polymetallic sulphides have been shown to include a diverse microbial community with remnant vent fauna and suspension feeders. Though they lack the dense population of active vent ecosystems, there are megafauna present that thus far have been found nowhere else.(1)

For cobalt-rich crusts, one recent high-quality evidence synthesis notes that they are incredibly diverse between and within ocean basins, making generalization extremely difficult. Irregular topography of these crusts makes for high spatial and temporal variability and, as a result, the synthesis notes that each seamount should be treated as a single ecological unit and described as such.(1) These habitats have shown to support biodiversity and play a role in biological enrichment, ocean productivity and carbon sequestration.(1) Crusts are also noted in one recent low-quality evidence synthesis to support forests of corral and sponges.(2)

Environmental consequences on fauna, biodiversity, ecosystems and ecosystem services both overall and by mineral and approach to mining

Direct and indirect impacts of mining in sea-bed ecosystems

One recent high-quality and two recent low-quality evidence synthesis describes that some evidence has been generated from small-scale, low-intensity experiments from nodule regions in the Clarion Clipperton Zone, however these have not been conducted for either active or inactive vents or cobalt-rich crusts.(1; 2) The evidence synthesis describes that the removal of resources from nodules will result in a decrease in habitat availability and loss of biodiversity, with the direct impact expected to be between 6 and 1(6),000 km^2 per nodule mine. The expected loss for the vents and crusts is relatively smaller, with the effects at vents predicted to be less than 10 km^2 per mine and for cobalt-crusts between 10-100 km^2 per mine.(1)

Two recent low-quality evidence syntheses describes how mining contractors propose to use a suction head to lift nodules directly off the seabed floor, which will result in the loss of hard substrates and seafloor integrity that support unique ecosystems.(6; 7) Another recent low-quality evidence synthesis notes that this will result in the destruction of most life within surface sediment layers of the mining site, which includes over 50% of megafauna that reside in the ecosystem.(2) With respect to timescales, a recent high-quality evidence synthesis highlighted that these disturbances remain over two to four decades later and can lead to local extinction of select species.(1) The same evidence synthesis describes that the recovery of some of these fauna as taking hundreds to thousands of years given the slow speed of their growth and is particularly impactful for nodule mining given the broad spatial scale of operations.(1) Mining in both active and inactive vents as well as cobalt-rich crusts is expected to have to remove fauna as well as the minerals likely leading to species extinction, however relatively less is known about the direct impacts on either habitat.(1)

One recent low-quality evidence synthesis examines the current knowledge about reproduction in deep-sea corals, which may be threatened by disturbances caused by deep-sea mining.(8) The synthesis highlights that coral in the North Atlantic region are among the most extensively studied, though the synthesis states that overall less than 7% of deep-sea coral have had any aspect of their reproduction studied.(8) The evidence synthesis describes the two main reproductive modes for coral being broadcast spawning (releasing gametes into the water) and brooding (internal development), also noting that deep-sea coral can take decades to centuries to reproduce. Further, the synthesis notes that reproduction for many species is linked to seasons and environmental cues.(8) The evidence synthesis provides details regarding what is known about the reproduction of different types of coral including scleractinians, antipatharians, alcyonaceans, pennatulaceans and stylasterids.(8)

One recent high-quality evidence synthesis found that the impacts of plumes are in part influenced by the intensity of mixing and the quantity of sediment that is discharged.(1) The synthesis notes that there is currently no publicly available data on mining-equipment tests which limits the understanding of sediment discharge and instead estimates are made based on projected resource extractions.(1) The impacts of plumes include that sediments may smother organism, impair the feeding of organisms and significantly change habitats for organisms in the midwater and at the seafloor.(1)

One recent high-quality evidence synthesis describes that relatively little is known about the impact of chemical substances and metals, however it does note that mining of sulphide deposits in vents are likely to have the highest potential for metal toxicity.(1) One recent low-quality evidence synthesis examined the evidence-base for metal toxicity in deep-sea invertebrates and identified that metal interaction can result in a range of negative consequences including modifications to the fauna endocrine functioning, immune system, respiration, DNA-damage and increased mortality.(9) The synthesis highlights that relatively few studies have been undertaken that measure actual metal concentrations in tissues in part due to sample sizes and difficulty maintaining deep-sea conditions in labs. As a result, there is relatively little understanding of how fauna adapt.(9) However, the evidence synthesis does identify a large range biomarkers to monitor environmental impacts organized by biomarkers for immune system processes, cellular metabolism processes, and oxidative stress processes.(9) Similarly, one recent medium-quality evidence synthesis reaffirms many of these findings and creates a modelling framework that may be used to understand the metal effects on marine species and support predictions regarding the impacts of deep-sea mining on marine food webs.(10)

One recent high-quality evidence synthesis states that deep-sea mining will increase noise, vibration and light, however little is known about the potential impacts, particularly in the sound fixing and ranging (SOFAR) channel.(1)

Management and mitigation measures for environmental impacts

One recent high-quality evidence synthesis notes that while monitoring is crucial, current knowledge gaps make it difficult to establish effective monitoring systems and indicators. (1) While contractors are required to produce both environmental impact assessments and environmental management and monitoring plans, one recent low-quality evidence synthesis notes that the current scientific gaps limit the effectiveness of any environmental assessments that are produced.(7) A further complication described in one recent low-quality evidence synthesis is the lack of clear definition of 'serious harm' in the regulations and the lack of science-based risk criteria that are needed to determine effective monitoring and mitigation efforts (7)

One recent high-quality evidence synthesis states there are currently no tested restoration techniques, however current mitigation measures include setting aside protected areas at both the individual mine and regional scale.(1) This has been in implemented in the Clarington Clipperton Zone, however it has been suggested that these may not be sufficient to deal with the variability in habitats and biogeochemical features across nodules.(1)

Timescales and recovery times

One recent high-quality evidence synthesis describes that resilience in nodules is expected to be very low with recovery requiring many decades and up to millions of years, with the presence of sediment potentially further slowing this recovery.(1) One recent low-quality evidence synthesis describes that older experiments (more than 20 years old) show little visible change in tracks, though some species have moved back into tracks and that there is very little recolonisation of disturbed areas over the decades.(2)

One recent high-quality evidence synthesis notes that for active hydrothermal vents, the variability of fauna makes generalizations about timescales across vents very difficult, but models estimate recovery is in the range of 20-100 years.(1) Little is known about baseline information on inactive sulphides to determine resilience.(1)

Public opinion and societal considerations

One recent low-quality evidence synthesis highlights that research on public attitudes about deep-sea mining is sparse and it is currently difficult to gauge the level of public awareness.(2) The evidence synthesis also notes challenges with a lack of representation of Indigenous peoples and coastal communities in the available evidence.(2) Finally, the synthesis notes that from a societal perspective it is challenging to compare terrestrial mining with deep-sea mining and that relatively few studies have tried.(2)

Economic considerations

With respect to the supply of minerals, one recent medium-quality evidence synthesis states that polymetallic nodules could hold over 6,000 million tonnes of manganese, 270 million tonnes of nickel and 4 million tonnes of cobalt.(4) While one recent low-quality evidence synthesis includes estimates that ferromanganese crusts in the 'prime crust zone' in the pacific ocean contain significant quantities of nickel and likely more manganese, cobalt and tellurium than terrestrial reserves.(2) The same synthesis indicated that estimates of polymetallic nodules grade, tonnage and abundance are largely informed by three resource assessments while only a single resource assessment has been conducted on polymetallic sulphides and ferromanganese crust-resource assessment remain in infancy.(2)

With respect to the demand for metals and minerals, two recent low-quality evidence syntheses describe modelling studies that predict the need for additional minerals to support the transition to electric vehicles and other forms of electromobility.(2; 7) One of the syntheses states that modelling studies note a risk of supply and demand imbalances occurring over the next decade, in part spurred by geopolitical and biodiversity concerns for terrestrial mining of nickel, cobalt and copper.(7) However, the other synthesis describes mineral demand projections as being subject to considerable uncertainty, reporting that the clean energy transition could require significant amounts more lithium, cobalt and nickel. (2) However, the evidence synthesis also indicated that there is currently no available evidence that demonstrates that terrestrial mining will be a constraint on supply, and instead concerns around geopolitical considerations and increasing energy consumption to mine deeper are largely driving discussions of deep-sea mining.(2) Further, the evidence synthesis highlights that considering recycling of minerals and the use of secondary raw materials is critical to factor into analyses.(2)

We also identified one older medium-quality evidence synthesis that examined the economic value of the deep sea.(11) The synthesis highlights that the value is dependent on how societal and economic choices interact with deep-sea resources.(11) The evidence synthesis, which includes a meta-analysis of 15 single studies, describes the overall functioning of the deep sea as being of high economic importance in comparison with the ecosystem of the open ocean, largely as a result of the critical ecosystem services (e.g., provision, regulating and cultural services) present in the deep sea.

Governance mechanisms for deep-sea mining

One recent low-quality evidence synthesis indicates that while international standards and obligations govern deep-sea mining including the UN convention on the law of the sea and the International Seabed Authority's regulatory framework, many coastal states have significant resources of deep-sea minerals located within their jurisdictions, which they can mine so long as they comply with obligations in the UN convention.(2) The synthesis also notes many of the governance challenges including the lack of clear definitions of 'serious harm' and 'significant adverse change to marine environment' pose significant issues to determining effective governance mechanisms that balance a risk-risk framing.(2) The synthesis highlights the importance of using the precautionary principle in the absence of greater scientific certainty.(2)

One recent low-quality evidence synthesis describes three complementary approaches that could be adopted as part of a governance framework moving forward:

- the precautionary approach which incorporates risk assessment methods to operationalize precautionary principles at the project level
- an ecosystem approach which uses models to determine relationships between ecosystem components and explain ecological feedback loops
- adaptive management which enabled the iterative reduction of uncertainty overtime through real-time monitoring and response to impacts.(7)

Finally, though only somewhat related to the impacts of deep-sea mining, one recent medium-quality evidence synthesis describes the development of an integrated multi-criteria decision-making method for evaluating and selecting sustainable deep-sea mining transport plans, including a suggestion for a series of evaluation criteria such as technical efficiency, technological maturity, reliability, capital cost, operation and maintenance cost, gas emissions and others.(12) The synthesis highlights that the model developed and its criteria can help to evaluate and rank transport plans in operation as well as to predict their performance on technological, economic and environmental and social impacts.(12)

Next steps based on the identified evidence

The literature related to deep-sea mining spans a wide range of disciplines including engineering, biology, environment and climate change, health, economics and political sciences (to name a few). As a result, determining what is known and where there are gaps in the literature is a significant undertaking and may be enabled by:

- the development of high-quality living evidence syntheses (and associated gap map) pertaining to some of the key areas of the organizing framework
- setting a structured global research agenda that specifies the wide range of questions that need to be answered
- learning as much as possible from existing exploration contracts and ongoing research efforts to map the baseline of the deep sea.

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