International Journal of
Georesources and **Environment**
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2018 **4**(**3**): 86-91
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

The Potentials of Scientific and Industrial Collaborations in the Field of REE through China's Belt and Road Initiative

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Abstract: Within the framework of trade deals and infrastructure investments, China also wants to build a "belt of scientific cooperation" with countries and international organisations involved in the Belt and Road Initiative. This could create an opportunity for involvement of several European countries that have so far treated China's initiative with skepticism about the coherence and practicality of the project. A crucial issue that concerns both China and the European Union in the recent years is the establishment of an undisrupted supply of critical raw materials to satisfy the consumption demands of the modern high-tech world that we live in. Among the listed critical raw materials are the rare earth elements (REE). Accordingly, the development of an extended and sustainable REE supply chain is a significant research field in which both sides could collaborate and benefit from. It is crucial for the involved countries to utilise their advantages, work together and share knowledge to tackle technical, economic and environmental issues that govern the global rare earth industry. Hence, in this paper the possibilities of a potential cooperation are investigated in the context of collaborative research projects, academic networking, workshops and training for young scientists. The aim is to seek, find and bridge any gaps that exist between the two sides with a view to strong academic and industrial collaborations.

Keywords: rare earth elements, REE supply chain, raw materials, scientific collaboration

1 Introduction

Rapid economic growth of the Chinese economy in the past decade and its potential for strong growth into the foreseeable future have turned China into an important exporter of capital, both in massive foreign exchange reserves as well as in direct investment (Du and Zhang 2018, Zhai 2018).

Looking forward, the governmental policies and initiatives will continue to help support the rapid expansion of the Chinese economy. Among them, the recent "Belt and Road Initiative" (BRI), otherwise known as "One Belt One Road", is likely the most significant in China's international economic policy and will provide fresh momentum to the economic growth of the country in the coming decades.

Launched in 2013 the Belt and Road Initiative is a series of potential interconnected bi-lateral trade deals and infrastructure projects that seek to establish enhanced trade routes and communication networks from China through other Asian countries to Europe and Africa (NDRC 2015). In its broadest definition, the BRI could cover more than 65 countries, 4.4 billion in population, and nearly 30% of the global GDP (Zhai 2018). In other words, it is an ambitious plan of the Chinese President Xi Jinping to revive the ancient Silk Road trade routes from Asia to Europe.

China intends to connect with the involved countries along several routes (NDRC 2015). The 'Belt' aims to link the less developed western regions of China through various economic corridors to Russia, Central Asia, and Europe. Meanwhile, the 'Road' is a sea route designed to link China's coastal provinces to Southeast and South Asia through the South China Sea and to Europe and Africa through the Indian Ocean, Persian Gulf and Mediterranean Sea (Figure 1).

China has also expressed interest in joint economic development in the Artic (NDRC 2017) and has introduced a third specific sea route through the Northern Sea for faster cargo transits between Europe and Asia (Figure 1).

With a monumental US$1.4 trillion worth of planned investments to build railways, ports and other infrastructure in involved countries along the aforementioned routes, the BRI is historically the biggest foreign investment strategy by any single country in world history; multiple times bigger than the Marshall Plan that was deployed to rebuild Europe in the post- World War II era (Cheng 2016, Zhai 2018).

China itself will naturally benefit from the new Silk Road as it will expand its trade connections with Europe, its biggest export market, and Africa, potentially the continent of future growth. Investment in countries along the way could help Chinese companies to expand abroad just as economic growth and heavy investments are slowing at home. The BRI would also promote the internationalisation of the Chinese currency and bolster China's political

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DOI: 10.15273/ijge.2018.03.015

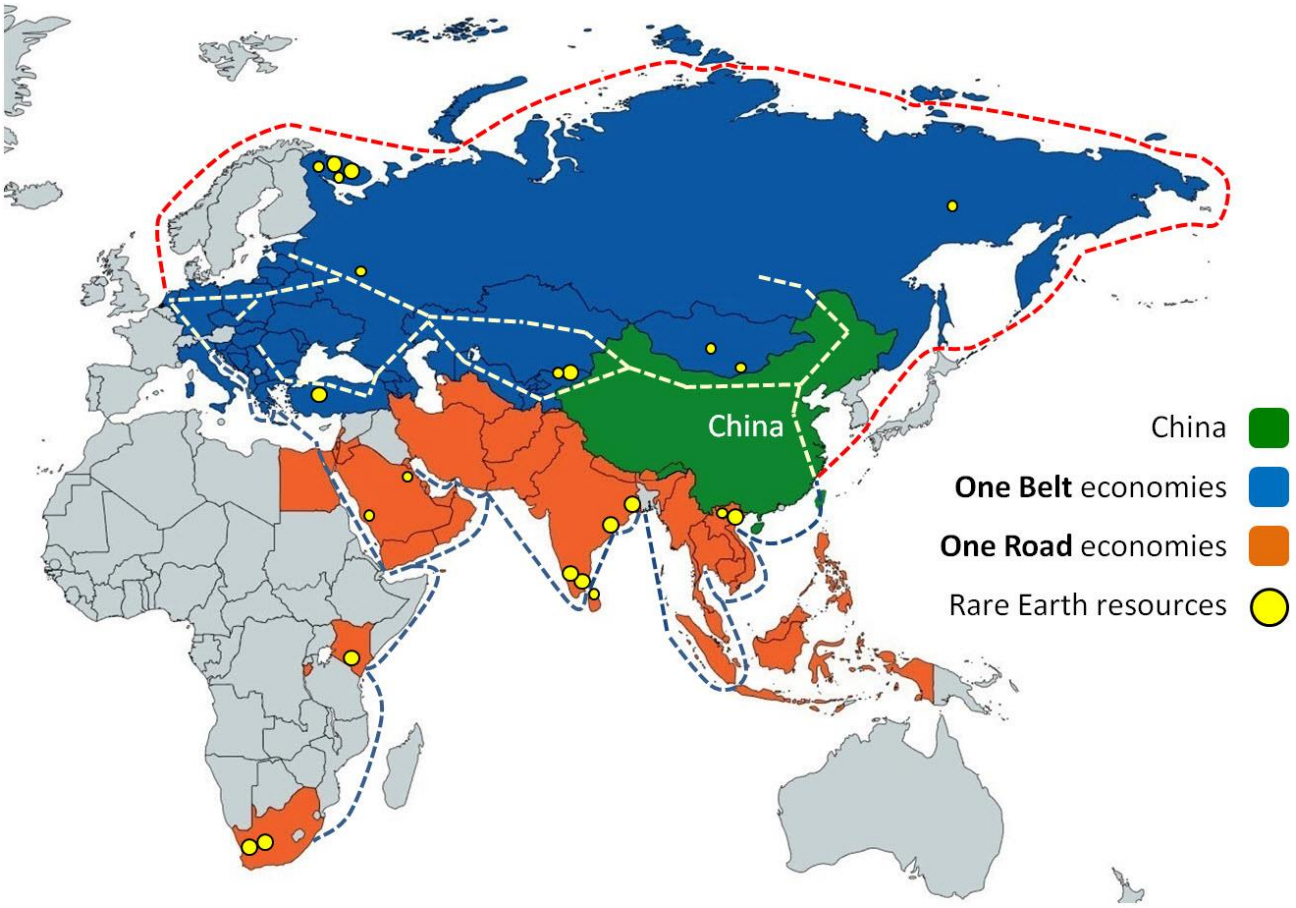

Figure 1 The Belt and Road Initiative Roadmap including REE sources found in countries involved

Influence abroad (Cheng 2016, Du and Zhang 2018).

However, the challenge for China is to convince other countries, especially in Europe, that the Initiative is a train worth jumping aboard and that it is not just an attempt to tie other countries into a China-centred production network.

Within the European Union there has been no unified perspective on the BRI. At the individual EU member state level, however, a large number of countries, mostly in the south, center, and east that have infrastructure deficits or pressing unemployment and economic growth challenges have already warmly embraced the initiative and have commenced cooperation (Herrero and Xu 2017). The Scandinavian countries have shown little interest so far, partially due to the fact that they are economically developed, well connected, and situated in a corner of Europe that sees, comparatively, little transit activity. Germany and The Netherlands have shown interest and have commenced engagement, yet at the same time they are evaluating the BRI's long-term strategic implications - mainly economic - at a national and EU level. Evidently, the level of interest shown already by several EU states in the Initiative will compel the European Union to come up with strategic policy decisions on BRI engagement.

In this instance, common ground needs to be found that will foster closer collaboration between China and the EU within the BRI framework. Such a case is the supply of critical raw materials, including the rare earth elements, to meet the consumption demands of our high-tech era.

As is well known, the monopolistic control of China over the global REE market remains unchangeable, while the EU is one of the biggest importers of rare earths from China (Barakos et al 2016a). Nevertheless, both China and the EU are dealing with issues that govern the REE industry in national and international level. Thus, cooperation may take place between the two sides in the context of the BRI framework to resolve all issues in the rare earths industry. This cooperation can be established in both an academic and industrial level.

This way, China can dissolve all doubts and prove its cooperative intentions that come with the development of the Belt and Road Initiative. Besides, China claims to seek not only for the commercial and industrial cooperation with the involved countries, but also the academic collaboration and exchange of knowledge through research projects and joint organisation of workshops and conferences.

2 Methodology

To be able to establish collaboration we first need to determine the issues that exist in the REE industry and how these can be solved. In this paper a first attempt is made to spot and analyse the basic problems that each side is facing.

Then a framework is developed with respect to the know-how that China and the EU have and thus, can

exchange with respect to solving the issues that have arisen.

Finally, this framework is used as a guide for potential academic and industrial collaboration between China and the EU in order to establish a balanced and transparent REE market and an undisrupted supply of rare earths.

3 Issues Facing the REE Industry

The world of rare earth elements is far more complex and cannot be scrutinized as easily as other commodities like copper, or coal. The REE industry has many features and is facing significant challenges that are differentiated locally.

3.1 REE issues in China

At the time of writing this paper China is accounting for almost 90% of the global REE production and 70% of the global consumption. By taking advantage of the large domestic REE resources and by implementing a carefully-crafted, dynamic long-term strategic plan, China is dominating the global REE industry for more than three decades (Barakos et al 2016b).

Nevertheless, the Chinese REE industry is facing big problems. In the aftermath of the REE crisis and price-spike of 2011 the interest for REE production has soared worldwide (Barakos et al 2016b), let alone inside of China. The prices plummeted in a short time and many of the potential producers around the world took a step back. In China, however, small-scale - mostly unregulated - mining flourished, thus raising issues to the domestic REE sector over the years (Shen et al 2017).

Illegal, unplanned production resulted in chains of black interests involving mining, processing, circulation and smuggling of rare earths outside of China (Packey and Kingsnorth 2016, Shen et al 2017). This has seriously disrupted the REE market order and led to a substantial decline in the prices of rare earth products. At the time of writing, the low level of prices has made extraction and processing of rare earths a money-losing business even for Chinese producers; only domestic downstream companies are still profitable (Packey and Kingsnorth 2016).

Furthermore, unregulated production has resulted into uncontrolled depletion of domestic REE resources. Given the transient nature of unregulated mining, illegal miners usually take only the high grade ore leaving the medium and low grade ores behind, unlike a regular mine plan that dictates the recovery through a mix of high, medium and low grade ores (Packey and Kingsnorth 2016).

Another consequence of illegal REE production is the serious damage that is caused to local ecosystems. Mining and processing of rare earths poses challenges and risks, let alone when it is unregulated. Their association with the radioactive elements thorium and uranium, as well as the use of dangerous chemicals and toxic compounds during REE processing demand expensive mitigation measures to ensure efficient environmental protection and workers' safety. At this point it should be mentioned that the environmental degradation in China comes as a result of lax regulations for both legal and illegal mining. In Baotou, Inner Mongolia, illegal mining has resulted in extended water pollution while in Ganzhou, Jiangxi, regulated yet excessive mining and extraction of rare earths have severely damaged the Dongjiang River (Shen et al 2017).

It is estimated that a kilogram of rare earths produced in China has an environmental cost of US $5.60, whereas the sale price of several individual REE like lanthanum, cerium and yttrium is currently lower than that. In addition to that, the cost of rehabilitating the REE mines, tailing dumps and disused processing facilities is more than tenfold the current gross revenue of the domestic rare earths industry (Packey and Kingsnorth 2016). Resultantly, the gap between the price and the true cost of rare earths is significant.

As part of its effort to protect domestic resources and the environment, the Chinese government has imposed export quotas and management measures on rare earths and related products (Barakos et al 2016a). This policy, however, did not confine illegal production, while it was identified as not conforming by the World Trade Organisation (WTO). After that, the Chinese government initiated a consolidation plan of the domestic REE industry; more than 67 REE mining licences and 99 REE processing companies are now controlled by a handful of state-owned enterprise groups (Packey and Kingsnorth 2016, Shen et al 2017). Howbeit, this plan has proved to be inadequate as well. Illegal production is constantly growing over the years and accounts for nearly 40-50% of the total production in China (Table 1).

Table 1 Illegal production of rare earths over the years in China (Packey and Kingsnorth 2016)

Year	Production in China	Illegal mining	ROW
2010	89,200 t	25-30,000 t	5,000 t
2011	93,800 t	25-30,000 t	6,000 t
2012	93,800 t	25-30,000 t	8,000 t
2013	105,000 t	25-35,000 t	12,000 t
2014	105,000 t	40-50,000 t	15,000 t
2015	105,000 t	70-90,000 t	19,000 t
2016	105,000 t	80-100,000 t	24,000 t

The ongoing export quotas on REE and related products are contributing towards the growing of illegal mining and smuggling out of China. If this continues, it will decrease the financial attractiveness to develop REE projects outside of China and will consequently lead the international community to continue purchasing rare earths at lower prices from smugglers.

3.2 REE issues in Europe

Unlike China, Europe should not be considered a producer but rather a major consumer of rare earths. It took a REE-crisis for the EU (and the rest of the world) to realise its full dependency on Chinese REE production and export quotas. Following the crisis, actions were taken, but the nosediving of the prices and their prolonged low level has affected the

European REE industry from its very first steps.

Yet, the main reason for not being able to make a difference in the global REE market is because of Europe's small output compared to China's overwhelming global monopoly.

There are a handful of REE-rich ore deposits found in Europe as well. Ongoing exploration activities primarily in Sweden and Greenland have resulted in the discovery of relatively big REE resources. However, it is difficult to say that these exploration projects can translate into active rare earth mines in the foreseeable future (Barakos et al 2016b).

This is supported by the high capital and operating costs and expensive measures of reducing risks associated with rare earth extraction and processing, and thus has resulted in the EU being a cog in the wheel of global REE production. For instance, the labour costs in Europe cannot be compared to the cheap labour in China, while the strict regulation framework that is implemented in all European countries further increases the level of costs for any potential REE mining and processing project.

On top of that, the European REE industry lags behind in know-how and production capacity when it comes to developing a fully integrated rare earth supply chain. It has taken more than three decades for China to achieve current capacities and capabilities in mining, processing, separating and refining rare earth elements and this is something that cannot be copied in a short term (Barakos et al 2016a). Without doubt, innovations have been accomplished and remarkable milestones have been reached in small scale processing and separation of REE and in finding new applications for them. This, however, apparently is not enough.

Last but not least among the issues that govern the REE industry in Europe is the acquisition of a social licence to operate. Terms like greenfield mining and responsible sourcing are included in all relevant legislation instruments in the EU showing how important it is to engage with the local and (general) EU community so as to ensure full agreement amongst all stakeholders and go beyond the NIMBY-syndrome (Not In My Back Yard). This policy has been further developed in the recent years as an aftereffect of the environmental problems in China.

4 A Collaboration Framework for the REE Industry

Apparently there are different issues but also some common problems that need to be resolved for both China and the EU. Contrary to the issues, there is expertise and know-how that one side can offer to the other in the collaborative context of the Belt and Road Initiative.

Thus, a framework is being developed hereinafter with respect to mutual beneficiation cooperation for the exploitation of REE resources and the smooth-running of the REE industry. This framework promotes collaboration in both a scientific and industrial environment.

4.1 Development of REE projects

As already mentioned, China plays host to a considerable amount of the world's proven rare earth reserves; nearly one third of them. Due to their depletion, however, China is constantly seeking to invest in foreign exploration REE projects. The most typical example of China's policy is the purchase of Mountain Pass in California by a Chinese-led consortium in mid-2017, meaning that Beijing will have an influence over the development and direction of the biggest U.S. REE resource from now on (Roskill 2017). Similarly, Chinese companies tried in the past years to acquire the majority stake of Lynas Corp. and Arafura Resources in Australia, but without success.

Accordingly, it could be said that China will be making direct investments in some of the countries involved in the BRI in order to secure supply of REE resources that have been found in these countries. Truth be told, there are some remarkable rare earth resources through the Belt and Road routes as illustrated in Figure 1. Russia, Vietnam and India hold the biggest REE resources among the countries that are covered by the BRI, while there are significant ongoing REE exploration activities in Kyrgyzstan, South Africa and Turkey (Table 2). Including China, the REE resources found in BRI countries exceed 50% of the world's total. It should be repeated here that Greenland and Sweden are hosting notable amounts of REE resources as well, but are not (yet) part of the Belt and Road Initiative consortium.

Table 2 Potential of REE Resources in BRI involved economies (Weng et al 2015, Zhou et al 2017)

	Country	REO (Mt)	%
Belt and Road Initiative Economies	China	164.34	34.37
	India	5.97	1.25
	Kenya	6.15	1.29
	Kyrgyzstan	1.60	0.34
	Mongolia	1.28	0.27
	Russia	48.16	10.07
	S. Arabia	0.94	0.19
	S. Africa	2.06	0.43
	Sri Lanka	0.001	0.0
	Turkey	0.48	0.1
	Vietnam	15.44	3.23
	Australia	49.12	10.27
	Brazil	53.38	11.17
	Canada	34.75	7.27
	Greenland	42.95	8.98
	Sweden	30.19	6.31
	USA	13.48	2.82
	ROW	7.82	1.64

Several countries involved in the Initiative are low-income economies. Yet, the rapid developments of economy and infrastructure construction shall increase the demands for mineral resources in these countries (Liu et al 2017). Therefore, the BRI provides an opportunity for mutual

beneficial cooperation to explore and exploit potential rare earth resources in these lands. Besides, there is potential for discovering new REE resources, among other commodities in unexplored areas and countries covered by the Initiative. Afghanistan and Pakistan are such two countries, whose unexplored mineral resources could become the bone of contention between several nations in the near future. Nevertheless, China would and should never plunge into such battlefields alone, due to the foreseeable risks and costs, especially in the view of their possible defection to the U.S.-led camp in Afghanistan for example (Cheng 2016). Collaboration with the EU in the context of the Belt and Road Initiative could ease the access to these countries' potentially valuable resources.

4.2 Industrial collaboration opportunities

Aside from policies and strategies, there can be cooperation also at the industrial level. The source of most problems, especially for China is the existence and constant growth of illegal REE mining. China failed to curb illegal REE producers even after the restructuring of its regulations and the consolidation of the domestic REE industry. This issue gives room to the EU to intervene and transfer its respective know-how to China.

The mining and processing of REE in Europe falls into the scope of a wide variety of EU directives that cover every aspect of potential risks in the REE industry sector (Barakos et al 2016c). The Mining Waste Directive (Directive, 2006/21/EC), is a significant legislation instrument for REE mining and for the management of groundwater. The Waste Framework Directive (Directive, 2008/98/EC) deals with solid wastes, while the Environmental Impact Assessment (Directive, 2011/92/EU) is the regulation where pit mines and quarries fall into. China's alignment with a regulation framework that is based on the European standards will contribute towards restricting unregulated REE mining and tackling the environmental disaster in the affected areas.

Another step towards this direction is the optimisation of the overall process through the automation of operations and digitalisation of all mining and processing activities. With the extended use of computer-integrated mining, the Chinese REE industry can be further consolidated, the uncontrolled depletion of REE reserves can be monitored efficiently, and the current erroneous practices that threaten the environment as well as the health and safety of staff and inhabitants can be reduced significantly. It could be well said that the respective cost is high compared to the cheap Chinese labour cost. Yet, the true cost that was mentioned previously and that includes the environmental cost of REE production will eventually be lower.

Digital effectiveness has become a top priority for mining companies and environmental agencies in Europe and the acquisition of know-how is now a valuable asset that the European Union could share with China.

The digitalisation of the REE industry in China could be well combined with the development of a vertically integrated REE supply chain in Europe. The evident lack of intellectual capital outside of China reinforces concerns and arguments regarding the potential of the European REE industry to compete with China and the capability to avoid environmental pollution with detrimental effects on local societies. There is limited availability of experienced staff to work in REE mines or processing plants. Hence, the EU relies upon China to transfer its REE processing, refining and fabricating know-how to Europe in the collaborative context of the Belt and Road Initiative.

4.3 Academic collaboration opportunities

Another perspective would be the scientific cooperation through the BRI. Given the nature of the aforementioned industrial cooperation potentials, there is plenty of room for interaction between academia and the REE industry. After all, China wants to build a "belt of scientific cooperation" as well with countries involved in the Initiative and aims to complete a basic cooperation network in science and technology by 2030 (NDRC 2015, 2017).

Since the initiative was proposed in 2013, the Chinese Academy of Sciences has expanded its global cooperation and outreach by providing technological support and services to help countries tackle practical issues. For example, the Digital Silk Road program was formally proposed in 2016 in order to bring together scientists from 40 countries to cooperate on space-based Earth observations that might help identify and manage natural resources, and protect the environment (Jia 2017).

Focusing on the REE research sector, there are several running projects in Europe that aim to give answers to research questions related with the market and the industry of rare earth elements. To give an instance, the EuRARE research project was funded by the European Commission for developing a sustainable exploitation scheme for Europe's REE ore deposits. Universities and research organisations from 10 countries all over Europe were part of this project. Furthermore, there are well established institutes like the Helmholtz Institute Freiberg in Germany that conducts research in all disciplines related to the REE (exploration, mining, processing, and recycling).

Simultaneously, there are well established institutes in China conducting research solely on rare earth elements. The Baotou Research Institute of Rare Earths, established in 1963 in Inner Mongolia, is the world's largest, employing about 700 people. Two other notable institutes are the State Key Laboratory of Rare Earth Materials Chemistry and Applications affiliate with Peking University, and the State Key Laboratory of Rare Earth Resource Utilization, affiliated with Changchun University in the province of Jilin and belonging to the Chinese Academy of Sciences.

As a result of this research flurry, there are thousands of scientific publications each year coming from scientists located in BRI involved countries and that are related to rare earths. Apparently, a big amount of these publications are coming from China and the EU. However, the independent publications outnumber the internationally co-authored papers (Jia 2017). Evidently there is no cooperation between Chinese and European research institutes and organisations, at least to the authors' knowledge.

This low collaboration level offers a great opportunity for China and the EU to foster joint innovative research on

the field of REE. The Initiative can be a solid platform for facilitating multinational research projects, international workshops, academic networking, joint, laboratories, and training for young scientists. Numerous foreign scholars have already visited the Chinese Academy of Sciences to take part in short-term research visits (Jia 2017); this could be done for scientists that conduct research on REE as well.

5 Concluding Remarks

Ultimately, there are several opportunities for collaboration between China and the EU even if these are still loosely defined in the BRI. Nevertheless, the inclusion of the Belt and Road Initiative in the Chinese constitution is a major step towards solidifying it as a core plan of action and proves that this concept has a significant place in China's foreign policy going forward.

However, this challenging plan involves notable risk. The political motivation in the Belt and Road initiative could run against commercial logic and genuine scientific or infrastructure needs in different countries, leading either to bad investment and financial losses, or to mismanagement and erroneous research practices.

The collaboration through the Initiative must be sincere and fair, and benefit every nation and all participants, especially in key areas such as the supply of raw materials. China needs to convince its potential partners and especially the EU of its intentions. The BRI is a platform on which the EU could definitely exercise some influence, for instance by assisting participating states with issues such as business reform and socioeconomic policies. There are countries in Asia in which there are concerns over overreliance on China through the BRI, and thus an economic behemoth like Europe could function as a counterweight.

When it comes to the key REE industry sector, it is important that China will reform its policy and be more cooperative. As described in this paper, there is plenty of room for joint research and industrial collaboration in the field of rare earths. A combination of know-how and its transfer also to low-income economies holding REE resources would be to the benefit of both China and the EU.

After all, what Europe seeks to gain from the BRI is not another link to the Chinese market but a fair and equal scientific, commercial and industrial cooperation. If the Belt and Road Initiative will be the basis for the formation of a supercontinent in terms of trade, distrust and competing visions between its members will only result in friction and greater potential for (proxy) conflict.

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