Georgia Essential Minerals (GEMs)

The Development of Georgia Critical Minerals Partnerships: An example from Kaolin Mining Operations SE USA

A White Paper Report of the First Meeting of Georgia Essential Minerals (GEMs-1)

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Summary

Novel resources of the rare earth elements (REE) were discovered recently in the kaolin ore deposits in the Georgia Coastal Plain. This discovery also showed that it is possible to coproduce significant amounts of REE during the normal course of mining and processing mined kaolin ore. REE are among the 50 critical minerals identified as being vital to technological and economic development and also on which we are dependent on international supplies per the United States Geological Survey. A partnership approach is needed to bring these metals from mine to market. And in doing so, it will address the need for reliable domestic supplies of the rare earth elements.

The coproduction, mining, extraction, and forming a saleable rare earth product is beyond the reach of any one group. A partnership is desirable given the many kinds of tasks involved to bring the REE from outcrop to market. Among the important tasks are the identification of the state-of-the-art mining operations to concentrate the REE and identification of extractive technologies to produce saleable REE materials from coproduced REE resources. The Georgia Critical Minerals Partnership is being created to derive plans to identify and to promote the technological developments needed for the coproduction of REE from mined kaolin, their extraction, and aggregation to form saleable mineral products. This Partnership will necessarily bring relevant academic, government, and industry to derive these plans and strategies to bring the mined coproduced rare earths to market. The Partnership will be a vehicle to derive the needs for funding for accomplish the characterization of REE resources, calculating the resource base of REE, identifying extractive technologies and saleable REE products. The Partnership will highlight the governmental resources needed for resource evaluation and constructive environmental stewardship to permit the mining and extraction of the coproduced REE. It is projected that amounts of the REE resources in the coproduced kaolin mine waste warrants co-oping with industry to bank their concentrates of coproduced REE. Finally, a trained workforce must be in-place to make these plans a reality. The needed workforce includes trade, technical, professional, and managerial ranks. Through this partnership and its plans to mine and create saleable REE mineral products, Georgia will be better positioned to accomplish both the attraction of the high-tech industry needing REE and to be able to provide locally sourced REE to these industries for their growth and development. This Partnership will hopefully serve as a model for other regions to follow.

Introduction

The use of new high-tech products, advanced technologies, and materials by modern society relies on having abundant sources of critical minerals (Federal Register, 2017; USGS 2022). For example, rare earth elements (REE) comprise many components in the automotive, battery, and communications industries. New resources of the REE have been uncovered recently from kaolin mine waste and from the associated sand units in the upper Georgia Coastal Plain. A monazite [(La, Ce, Nd, U, Th) phosphate] sand product is being co-produced from Ti-Zr ancient beach sands in southeastern GA (Bailey, 2021; Oladeni, 2022; Al-Zehhawi, 2023). This site is one of only two REE producing sites in the United States (U.S.). The Georgia State Government is working to attract new industries that would need and rely on reliable supplies of REE and other critical minerals such as Ti and Zr. The further development of these new industries and related economic and job growth provide a compelling reason for having reliable domestic supplies of the REE and other critical metals. This White Paper is a report of the first meeting of Georgia Essential Minerals (GEMs) Workshop and describes the emerging Georgia Critical Minerals Partnership among academic-government-industry to accomplish the goal of producing reliable supplies of the REE and other critical minerals from the Georgia Coastal Plain. This partnership might serve as a model for other regions of the world looking to meet their needs for critical minerals such as rare earth metals and/or other critical metals.

Building the Georgia Critical Minerals Partnership

It is useful to note that the authors of this report were the initiators for this emerging partnership and were first brought together by recently realized common threads that included all being part of geoscience/Earth science departments in Georgia's public R1 universities and having a record of engaging in research on REE and mining. Our collective experiences included the characterization of critical mineral speciation in complex heterogeneous matrices, as well as waste valorization such as REE extraction from coal fly ash and municipal solid waste incineration ash (Liu et al., 2023; Wen et al., 2024) and recently issued patents on concentrating critical minerals from these geologic and mine waste materials (Tang et al., 2023; Elliott et al., 2020). Other experiences included over 30 years of working with the major kaolin producing industries in Georgia and connecting our students with the Georgia mining community and employers. Specific foci included the study of REE occurrences in Georgia kaolins (Boxleiter and Elliott, 2023; Elliott et al., 2018), REE occurrences in volcanic systems (Karpov et al., 2019), and REE in weathered rocks of the SE U.S. Piedmont (Schroeder et al., 2022). Thus, our own research and teaching interests when taken together provided the impetus to study further the geologic occurrences of REE, to derive methods needed to concentrate and extract REE from geologic materials, to think larger to integrate our thoughts with industry partners to help us accomplish our research and teaching, and finally to speculate how our efforts would support Georgia's ongoing interests in attracting high-tech industries.

We enlisted the Georgia Mining Association (GMA) to connect with industry in a significant way by liaising with their leaders. The GMA's mission is *"to advance and encourage the mineral resource industries ... to provide information on legislative matters to the membership and to create a better understanding among the people about the importance of the mining industry."* Lastly, our university system vision statements additionally helped us to unify this collaborative effort. For example, the University System of Georgia's mission is "*to excel in meeting the needs of our state and economy through universities and colleges that: provide an affordable, accessible and high-quality education; promote lifelong success of students; and create, disseminate, and apply knowledge for the advancement of our state, nation and world."* The study of critical minerals presents a novel opportunity for the geosciences departments in the three Georgia R1 universities to collaborate with industry and government on this societally pressing problem whose solution(s) will have wide impact locally in Georgia. The solutions derived will be impactful nationally and internationally as well.

With these starting points, and with the support from each of our home university research administrations, we engaged industry, academic, and government communities on February 1, 2024, at the University of Georgia Conference Center for the first Georgia Essentials Minerals Conference (GEMs-1). This conference enabled us to begin to think collaboratively regarding the occurrences of REE in the Georgia Coastal Plain, their abundances, their valuation, and ways in which these metals could be brought to market (resources to reserves). Forty-five participants[1] evenly balanced with numbers of academic (faculty and students from the University of Georgia, Georgia Institute of Technology, and Georgia State University), federal and state governments, and Georgia-based industry, with a focus on the evaluation of the potential to extract REE from production streams, overburden, and mine-tailings associated with the world-class kaolin and titanium mines in Georgia Coastal Plain. Students also attended as we hoped this meeting would enhance their interest and work in critical minerals. The outcomes consisted of four keynote addresses and breakout sessions. The following take-home points were seen as the most relevant and productive toward developing the Georgia Critical Minerals Partnership.

Firstly, there is considerable knowledge that has been gathered about the occurrences of the critical minerals (REE specifically) in the Georgia Coastal Plain from recent studies. These studies described how geologic processes have concentrated the REE resources in various geologic settings and mine waste products. These settings include alluvial sediments, regolith, sandstones, beach placers, and mined kaolin/bauxite ore (Bern et al., 2016; Bern et al., 2017; Epperson et al, 2018; Elliott et al., 2018; Cheshire et al., 2018; Shafer and Elliott, 2021; Oladeni et al., 2021; Schroeder et al., 2022; Boxleiter and Elliott, 2023). A rich body of peer-reviewed REE literature exists and we needed not to have recursive revelations. These studies indicated that REE occurr in some combination of detrital minerals, and secondarily formed phosphate and hydroxide minerals/overgrowths on existing detrital and clay minerals. Ongoing studies by Elliott and Tang, funded by NSF, are addressing the occurrence and fractionation of REE in the bauxite layers found within the kaolins. This work is also testing the hypothesis for the presence of ion-sorbed REE in these settings.

The presence of REE-bearing minerals and ion-sorbed REE must be considered in order to develop strategies to liberate the REE-bearing phases from host rocks, extract REE from their mineral hosts, and recover REE to generate final products (e.g., oxides). While the concentrating processes are known and being implemented in the creation of a monazite sand product from the Zr-Ti mining the southern U.S. Coastal Plain, the liberation of REE from mineral hosts and the recovery of REE will be intensive from a chemical separation standpoint. The concentration of the REE minerals is seen as an important first step and one that is tractable with low environmental risk. As

[1] A list of participants is given in Appendix 1.

an example, a heavy mineral subfraction was concentrated from kaolin mine waste resulting in a 100+ fold increase in the total REE (Elliott et al., 2018; Elliott et al., 2020; Boxleiter and Elliott, 2023). The technologically important heavy REE (HREE, including Gd-Lu and Y) were highly concentrated by 100-fold relative to their concentrations in upper continental crust and to the mine waste itself. An attempt to derive a dollar value was done for the 10 tons of a heavy mineral fraction (ΣREE = 5000 ppm for the Buffalo Creek mined kaolin; Elliott et al., 2018) of kaolin mine waste. Ten tons of a heavy subfraction of kaolin mine waste was valued at $990k with some considerable assumptions. The ten tons of a heavy mineral subfraction can be produced in the routine processing of mined kaolin in Georgia.

It is likely that kaolin streams will include overburden, grits, mine tailings, and other complex REE-mineral associations. These complex mixtures will require multifaceted approaches using analytical resources at universities, insights from industry, consultation with state-federal environmental agencies, and national government laboratories. There are numerous opportunities to route feedstock into, not only specific REE yields, but also byproducts that can be directed to other profitable uses that maintain cradle-to-grave materials that protect our environment (Hochella et al., 2019). The research experiences with extracting REE from coal fly ash and municipal solid waste incineration ash, points to the numerous steps and energy required to reach economic viability to bring REE metals to market (Liu et al., 2023; Wen et al., 2024). We remain optimistic that the solutions can be derived best from a partnership approach.

Secondly, the derivation of tonnage of critical minerals is necessary to develop further the separation and extractive technologies. The derivation of accurate tonnages of the REE is difficult given the heterogeneity of the REE occurrences within the region and within an outcrop or event stratigraphic bed. For instance, even in mining the kaolin, the mining communities make considerable effort to identify the zones containing kaolin ore and their grades well before the kaolin gets excavated and sent for further processing. Pathfinder elements (P, Ti, Zr, radiation survey) would be needed to pinpoint concentrations of the REE in kaolins, bauxites, and the interbedded sands. For the REE being sorbed on mineral surfaces or concentrated as REE-bearing minerals (e.g., monazite, xenotime), this distribution is even more complex at an outcrop/quarry scale. The derivation of the tonnage requires the collaboration of industry, research, and government communities. Such knowledge will lead to an improved understanding and planning for these REE resources. The use of airborne technologies may be especially helpful (Shah et al., 2017) to define zones of REE enrichment and to quantify the REE tonnages in the SE Coastal Plain.

As a third significant take-away point, it is tempting to think of one type of mined source to supply domestic REE (e.g., Mountain Pass, CA). The reality is that the anticipated tonnage at first approximation from a given quarry or even rock type itself might not provide sufficient REE to warrant the direct mining of that quarry for its REE. Hence, the REE are being identified as co-produced resources from kaolin mining, which is a different approach than mining a deposit primarily for REE. It was proposed that individual producers of the co-produced REE resources could pool their REE resources to a few numbers of separation facilities to produce a REE concentrate for further extraction and processing. For example, a monazite sand is produced as a byproduct of Ti and Zr mining from ancient beach sands in SE Georgia (Bailey, 2021). This monazite sand is sent to Energy Fuels in Utah, where U and Th are stripped from the monazite.

The residue is sent to Estonia to recover the REE. In a related scenario, small scale producers may participate in co-operative scenarios to build "banks" like co-ops used in agricultural markets. Additionally, the prospect of "mining" REE from existing products was encouraged. This recycling adds REE to the envisioned co-op REE banks derived from kaolin mining ore streams and other coproduced sources. The added REE may come from recycling and co-processing of waste from REE-bearing end products (e.g., electronics, scrap magnets, etc).

Lastly, regulatory oversight needs to be evaluated at both state and federal levels to be aware of barriers and overcome challenges that might lead to undesired economic and/or environmental impacts. These challenges must be understood along with the costs and benefits of separating these metals from co-produced concentrates of Coastal Plain sediments and mine wastes. As they are resources (not reserves), the increases in price will warrant further consideration to separate and process further the REE from these Coastal Plain sediments. The investment must be shown to be worth the risks, environmentally speaking, to air, soil, and water resources. The partnership of industry-academic-government is important toward deriving the best way(s) to mine, concentrate, and separate the REE from their host rocks.

Recommendations

The goal of extracting REE from the Georgia Coastal Plain sediments is beyond the reach of one academic lab and one mine/company in one industry. The attainment of the goal to be able to co-produce REE from Georgia Coastal Plain sediments will also require the collaboration with government to ensure compliance with laws and regulations governing mining and reclamation of land. Hence, a Critical Minerals Partnership is needed to make the goal of mining and extraction of REE a reality. The outcomes from this workshop led to the following recommendations, which are helpful to initiate and formulate this Partnership.

The Georgia State Geological Survey must actively engage national resources such as the U.S. Geological Survey. Engagement with the USGS and Georgia State Geological Survey is needed for accurate valuation as well as increased geologic knowledge of those REE resources.

Basic research needs to be continued and supported by industry-academic-federal partnerships to characterize and understand the nature of REE in coastal plain sedimentary rocks. The collaborations, initially supported by industry and later federal funding (e.g., NSF and DOE), have paid dividends already identifying REE resources that can be realized via coproduction of existing geologic resources (kaolins, bauxites, alluvial sediments, beach sands, and sandstones).

The proposed Georgia Critical Minerals Partnership will seek to accomplish the goals of having sustained production of critical minerals from the Georgia Coastal Plain. This primary goal is consistent with national goals such as creating reliable domestic supplies of the critical minerals. This goal is also consistent with the goals of the larger U.S. Department of State Minerals Security Partnership (MSP) whose goals are to "*to accelerate the development of diverse and sustainable critical energy minerals supply chains through working with host governments and industry to facilitate targeted financial and diplomatic support for strategic projects along the value chain*".

Continue to convene workshops (such as Georgia Essential Minerals, GEMs) to bring stakeholders together, prioritize, and address research and economic topics, provide continuing education for existing workforce, and train the next generation of people to carry forward the knowledge needed for sustainable growth.

Final Remarks

These efforts to learn about the REE in the kaolin mine waste thus far would not have been possible without industry and NSF supports. These supports included samples of mined and waste materials, access to quarry and processing facilities, a receptiveness to critical minerals research by mining companies primarily invested in other mineral products (kaolin, bauxite, Ti-Zr), as well as funds for chemical/mineralogical analyses and student support. These efforts have led to good publications, patents, and the prospect that these REE can be brought to market for the influx of high-tech industry being attracted to Georgia. The lesson of REE co-production from existing mining streams (kaolin, and Ti/Zr sands) is an excellent lesson for our students.

Academic-industry-government collaboration is much needed to create reliable and locally sourced, domestic supplies of the REE. These reliable domestic supplies are needed to support state economic development of high-tech industries. Georgia (and SE U.S.) might be in an enviable position of having both co-produced REE and high-tech industries being attracted to this state to use these REE. These new high-tech industries and anticipated new mining and processing will require the development of a workforce and additional employment ranging from technical to professional and managerial levels. Support for local sourcing of the REE and other critical minerals provides additional revenue. It may also decrease reliance on international sources for the REE critical minerals.

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Appendix 1. February 1, 2024, GEMs Participant List

Ashcraft, Joell	Georgia State University
Augusto, John	Georgia State University
Avant, David Jr.	Southeastern Performance Minerals
Babaie, Hassan	Georgia State University
Bevill, Jim	Carbo Ceramics
Boxleiter, Anthony	Georgia State University
Bromley, Chuck	Rayonier
Coughlan, Michael	Georgia Environmental Protection Division
Crabb, Andy	Thiele Kaolin Company
Davarpanah, Armita	Spelman College
Dutta, Avishek	University of Georgia
Elliott, W. Crawford	Georgia State University
Fagouri, Chris	Burgess Pigment
Falkowski, Joshua	University of Georgia
Garing, Charlotte	University of Georgia
Hooper, Geoffery	Georgia State University
Jones, Jamey	United States Geological Survey
Kaplan, Daniel	University of Georgia
Kenkare, Nirupama	IMERYS
Kuhn, Andrew	Mineral Technologies
Lamb, Jodi	Carbo Ceramics
Lancaster, Jamie	Georgia Environmental Protection Division
Lemke, Lee	Georgia Mining Association
Lieuwen, Timothy	Strategic Energy Institute, Georgia Institute of Technology
Malla, Prakash	Thiele Kaolin Company
May, Andrew	IMERYS
McWilliams, Melissa	Bulk Chemical Services
Melear, Nathan	University of Georgia
Merkley, Brett	Active Minerals International
Milewski, Adam	University of Georgia
Parrish, Eric	KaMin LLC
Pearson, Heather	University of Georgia
Renner, James	Chemours
Riley, Ed	Thiele Kaolin Company
Sanders, Monty	IMERYS
Schroeder, Paul	University of Georgia
Swanger, Todd	IMERYS
Tang, Yuanzhi	Georgia Institute of Technology
Thompson, Aaron	University of Georgia
Washington, John	US Environmental Protection Agency
Wen, Yinghao	Georgia Institute of Technology
Xu, Han	Georgia Institute of Technology
Yeboah, Nortey	Southern Company