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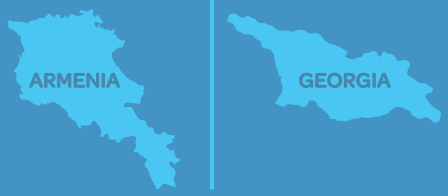

The
INTERNATIONAL WORKSHOP
On

BIOLOGY AND BIOTECHNOLOGY OF THERMOPHILIC MICROORGANISMS

CONTENTS

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PREFACE

An International Workshop on Biology and Biotechnology of Thermophilic Microorganisms held in Georgia and Armenia in October of 2015 was jointly funded by the National Science Foundation (NSF) and Georgia's Innovation and Technology Agency (GITA), and jointly organized and conducted by NSF, GITA, and the Armenian National Academy of Sciences.

NSF aspirations with the workshop went far beyond an ordinary conference agenda. This novel workshop combined traditional conference/workshop presentations and discussions with several unusual functions that are typically difficult to blend.

By design this workshop aimed at scientific discussions focused on biotechnology and site visits to local research institutions and natural sites. Brainstorming sessions with high level officials took place in each country. A working dialog between NSF and local government funding agencies was openly established. Expert evaluation of the status of thermophilic microorganism research programs in Georgia and Armenia was performed for potentially launching collaborations between US and Caucasus region researchers and institutions. In a sense the workshop itself was an experiment with many tiers of goals set forth for the workshop that prompted its structure and organization. Clearly, each party involved (GITA, Armbiotechnology Scientific and Production Center, NSF, and the workshop organizing committee) pursued their own interests. For example, GITA was mostly interested in presenting the best Georgian research programs to the American visitors, in establishing collaborations with the US institutions, and in demonstrating to the local funding agencies and stakeholders the importance of international cooperation with lead researchers in the biotech field. NSF's charge to the PI and the organizing committee was mostly related to (a) collecting and analyzing information regarding readiness of the region to play on the global scale and (b) to identifying science or technology niches in which US collaboration with Georgian and/or Armenian researchers would be mutually beneficial.

The workshop did not focus on a comparison of Georgian and Armenian research, education systems and organizations, and hence the similarities and disparities that appear in the report are intended as illustrations only. As Georgia and Armenia maintain cordial relations it is not surprising that they share many common features, such as the state border, a Soviet past, and a long history of mutual trade connections that unite these countries. Their focus on biotechnology essentially led us to link the two back-to-back trips into one workshop.

Both Georgia and Armenia are going through a complex modernization process of their national science and education, which is strongly affected by the aftermath of the collapse of the Soviet Union, current economic and political challenges, recent military hardships, and consequent significant changes in international relationships.

The Russian-Georgian war (2008) led to breaking most of Georgia's ties with Russian entities and resulted in putting an end to all science, education, and innovation relationships between Georgia and Russia. Georgian officials in government, industry and education are now trying to establish an integrated innovation-led research and education system nearly from scratch and they are looking for viable models in the West. They realize that close collaborations with Western researchers are imperative for fostering increased research productivity, for creating an entrepreneurial, modern knowledge-based economy, and for catalyzing progress in science and technology.

They recognize that Georgia is a relatively small country and hence they have to utilize a highly selective approach in setting their national priorities in innovation, science, and technology to gain a noticeable position on a global scale. The recently developed strategy of economic development through targeted support for research and innovation seems to be on a right track. The cornerstone of this strategy puts forward biotechnology as a priority in Georgia.

The Nagorno-Karabakh War with neighboring Azerbaijan and Armenia (1991-1994) dominated the region's politics throughout the 1990s and crippled Armenia's economy. Due to its position between Azerbaijan and Turkey, two unfriendly neighbors, Armenia maintains close security ties with Russia. This continues to have an evident influence on all aspects of life in Armenia, including research and education, which essentially inherited Soviet traditions of a strong fundamental University curriculum. The Panel members noticed some equipment at laboratories that was purchased about 30-40 years ago and is well-maintained and still in-use along with modern tools. During Soviet times, Armenian institutions (e.g., Institute of Microbiology, NAS, Armbiotechnology Institute, Charentsavan Lysine plant) played a leading role in the Caucasus region in the development of biotechnology by performing fundamental and applied research. In the meantime, several Soviet republics (e.g., Russia, Ukraine, Belorussia, and Latvia) were responsible for the tech transfer to scale it up and to turn it into manufacturing. With the collapse of the

Soviet Union, these relationships broke up, leaving Armenian biotech in isolation. Now, the Armenian researchers are looking to the West in order to strengthen the country's economy, to catalyze innovation and reinvigorate Armenian-made manufacturing while trying to capitalize on their traditionally rigorous education system. Government funding of research and development in Armenia is modest.

We cordially thank Dr. Tatiana Vishnivetskaya, the principal investigator, who led the organizing committee of this exploratory workshop, Dr. Francine Perler, who took on the major responsibility for editing the entire report, and the group of the invited participants, thereafter referred to as the NSF Panel, who did an excellent job analyzing the materials presented to them, provided invaluable insight, and formulated specific recommendations to NSF. The scope of this analysis was intentionally limited to exploring collections of thermophilic microorganisms, surveying natural resources with potential for the discovery of novel thermophiles, and evaluating thermophilic microbiology research programs in both countries.

We would like to emphasize that the novelty of the workshop organization rests in balancing a multifunctional approach with a load of reachable goals and a plethora of anticipated outcomes. It is the vast experience in science management, review and evaluation of research programs, collaborative centers, and large facilities accumulated during our tenure at NSF that inspired us to come up with the idea of combining different modes of assessment. Personal interactions of US scientists with foreign researchers are necessary to establish important ties and foster further collaborations. To perform the most comprehensive evaluation possible under the circumstances and to ensure a diversity of opinions, it was imperative for the US workshop participants to have broad, interdisciplinary, and complementary expertise in a general component of the field of biotechnology. The team of participants was able to perform the multileveled, requested tasks exceptionally well in a foreign environment, far outside of their comfort zone. The workshop organizers and NSF Panel successfully augmented the conventional conference with the evaluation and assessment of fairly large biotechnology research programs in two foreign countries.

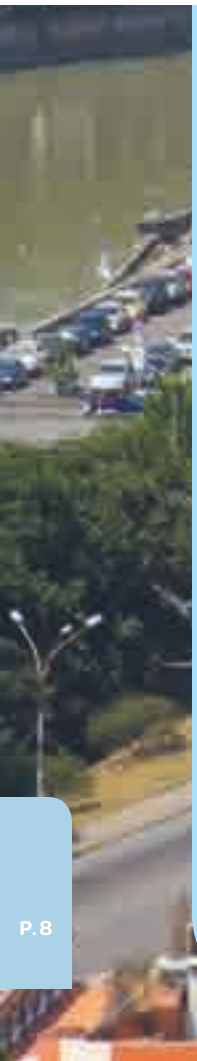
We think that such evaluations are vital for NSF strategic planning prior to establishing new initiatives, instituting international arrangements, and forging new relationships with the counterpart agencies abroad and with international research or policy organizations. There is no better way to get an accurate picture than an expert Panel's unfiltered observations.

We envision that the material and conclusions summarized in this report will be useful for NSF and other US government agencies as well as for Georgian and Armenian governments.

Maija M. Kukla and Alex Simonian | NSF Program Directors

EXECUTIVE SUMMARY

An international workshop was held in Georgia and Armenia for the purpose of evaluating their thermophilic microbiology research programs and the potential to establish beneficial new collaborations. The scope of this analysis was limited to (i) existing collections of thermophilic microorganisms, (ii) natural resources with potential for the discovery of novel thermophiles, and (iii) basic or applied thermophilic microbiology research programs.



The workshop format was similar in both countries with a symposium comprising local and US speakers, site visits to local scientific institutions, site visits to natural environments, and cultural components to build understanding amongst the participants. The NSF expert Panel consisted of ten US scientists, mostly with basic science backgrounds, running the gamut from graduate students to professors to retired personnel. The Armenian participants mirrored the composition of the US Panel with the addition of high level institutional and government representatives, while the Georgian participants consisted of distinguished senior scientists and government officials (including Ministers and representatives of Georgia's Innovation and Technology Agency), but no students or young faculty. The Panel and NSF Program Directors also met with high-level officials of the universities and institutes visited in both countries. In Georgia, the Panel visited a single institute that was part of a private university (Durmishidze Institute of Biochemistry and Biotechnology at the Agricultural University of Georgia) whose primary focus is applied research and biotechnology. In Armenia, the Panel visited a biotechnology institute (Armbiotechnology) and a public university (Yerevan State University).

The NSF Panel observed culture collections in each country. The applied focus in Georgia was mirrored in strain collections that were more suitable for biotechnology than basic research. In industry, strain characterizations are often limited to desired properties until the value of the strain is demonstrated. However, both industry and academics require an accurate knowledge of where strains were isolated. No culture collection catalog was available for examination in Georgia, although a database of isolates was maintained previously. There was a lack of common

modern parameters such as DNA sequence-based strain identification for Georgian isolates. Essential metadata for the isolation site and culture conditions may currently exist only in field and laboratory notes. The Georgian scientists were aware of these limitations, but they were unable to remedy the problem possibly because of their more applied focus combined with a lack of funds and technical resources (training, supplies and equipment). The condition of the culture collections in Armenia was quite good. The Armbiotechnology collection was accredited by the World Federation of Culture Collections and included much of the data required to be a useful resource for local and international scientists. Having an accredited culture collection with strain characteristics is important for stimulating local and international collaborations.

The focus of the workshop was on thermophilic microorganisms and local sites for their collection. In Georgia, instead of thermal hot springs the Panel visited a hypersaline lake and 'hot soil' habitats where the temperature could reportedly rise to over 55°C during summer. The Panel did not have an opportunity to visit a laboratory focused on thermophilic bacteria, but met with scientists studying thermophilic fungi. In Armenia, the Panel heard talks about thermophiles, visited laboratories studying thermophilic bacteria and visited a hot spring associated with a geothermal well.

Both countries had strong programs in applied microbiology and biotechnology. They generally reflected the current hot topics in biotechnology along with targets that were specific to each country. These applied programs were superficially evaluated due to the limited time spent on each potential lead target. Each country had programs worthy of further analysis by both (1) a scientific expert Panel to evaluate detailed presentations (written and oral) of specific projects and (2) an expert Panel that could assist in evaluation and prioritizing applied biotechnology projects with respect to market potential and comparison to current gold standards. Georgia's Innovation and Technology Agency is well suited to guide these efforts. Applied research in Armenia would benefit from a national agency promoting biotechnology and innovation, if one does not already exist.

The Panel's impressions were based on its limited exposure to the full repertoire of thermophile microbiology research in each country. In Georgia, the Panel only observed applied research programs. As a result, the Panel thought that basic research and microbial diversity analyses needed strengthening. Methods of analysis reflected more classical approaches. The Panel recommended collaboration and training abroad to maintain a high level of experimentation and to help modernize the classical methods observed in Georgia.

The Panel was pleasantly surprised at the focus on modern education and research methods observed in Armenia. The Panel met many young Armenian scientists, some of whom had trained abroad and/or had fruitful collaborations with international scientists. The Panel recommended continued collaboration and training abroad to maintain the high level of experimentation observed in Armenia.

In both countries, the Panel thought that increased funding of scientists and of research would significantly draw the best and brightest young people into science to insure its future as a valuable resource for each country. The Panel thought that each country provided different opportunities to establish new collaborations between US and Georgian or Armenian scientists that would indeed yield near-term achievements.

PREAMBLE

The international workshop "Biology and Biotechnology of Thermophilic Microorganisms" held on October 4-10, 2015 combined separate international meetings in Georgia and Armenia. Each meeting consisted of a daylong formal symposium with presentations by NSF supported expert Panel members from the US and local scientists, combined with two days of informal interactions during site visits to universities, institutes and typical natural resource locations.

The Georgia and Armenia meetings were united by similar aims:

1. Exploring existing collections of thermophilic microorganisms in these countries

2. Evaluating natural resources for the discovery of novel microorganisms important for microbiology and/or biotechnology

3. Exploring opportunities to establish new collaborations between US, Georgian and Armenian scientists, and identifying collaborations that would yield the greatest near-term achievements.

Two NSF Program Directors and an NSF support expert Panel of ten US scientists met with participants from Georgia or Armenia during the formal presentations and the informal scientific and cultural events. The NSF Panel members included faculty, staff and students from the broad US academic community, the Bigelow Laboratory for Ocean Sciences and industry.

The Georgian delegation consisted of mainly senior personnel from government, Georgia's Innovation and Technology Agency (GITA) and academics. The Panel only met with applied scientists from the Durmishidze Institute of Biochemistry and Biotechnology (DIBB), which is part of the private Agricultural University of Georgia (AUG). The Panel did not visit any public universities in Georgia. The Panel's analysis and evaluation of Georgian microbiology and biotechnology is based on interactions with three AUG laboratories. Therefore, this report and its recommendations may not fully reflect the state of science throughout Georgia.

The Armenian delegation consisted of senior government representatives and scientists from all levels of academic and biotechnology institutes. The Panel met with scientists from the Scientific Production Center Armbiotechnology (Armbiotech) and Yerevan State University (YSU). The symposium presentation by Professor Armen Trchounian described the overall education program at YSU. The Panel's analysis and evaluation was limited to a few laboratories at these two Armenian institutions. As such, this report and its recommendations may not fully reflect the state of science throughout Armenia.

During the workshop, working groups (consisting of Panel members and local delegates) were engaged in intensive and dynamic discussions in three main areas:

1. Microbial diversity, biology and genetics of thermophilic microorganisms including cellulolytic bacteria, probiotic microbes, phage and fungi, to name a few
2. Next generation –omics approaches for studying inhabitants of thermal environments
3. Application of thermophilic microorganisms and their enzymes in biotechnology, bioremediation, biofuels, probiotics, antimicrobials, metabolic products and other areas.

This report separately summarizes for each country:

- Discussions amongst the Panel and local representatives
- The Panel's scientific and technical analyses of the status of strain collections, basic microbiological research and applied research
- Panel recommendations to enhance science and biotechnology in Georgia and Armenia.

This report does not include evaluation of research presented by the US scientists, since its focus is science in Georgia and Armenia

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Over 60 Georgian scientists attended the symposium with presentations by US and Georgian scientists

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Approximately 40 Armenian scientists attended the symposium with presentations by Panel and Armenian scientists, including all levels of university professors, staff and 15 students

Eight posters were presented by Armenian students during the symposium poster sessions

GEORGIA

WORKSHOP

TBILISI

OCTOBER
5-7
2015

THE WORKSHOP IN GEORGIA

The US participants and over 60 scientists from different Georgian institutions assembled in the Vere Palace Hotel conference hall, Tbilisi, Georgia on October 5, 2015 to take part in plenary sessions and discussions. Minister of Economy and Sustainable Development, Dimitry Kumsishvili, opened the symposium portion of the workshop, which was spotlighted by multiple media outlets, including numerous national television stations, radio stations and newspapers. The Agenda for the Georgia workshop including listings of speaker names and presentation titles, plus listings of site visits and cultural events can be found in Appendix 1.

Prior to the symposium on October 5, the US Panel and the NSF Program Directors visited the Durmishidze Institute of Biochemistry and Biotechnology (DIBB), which is part of the Agricultural University of Georgia (AUG), where they heard informal presentations and talked to scientists in the laboratories of Professors Gagelidze, Sadunishvili and Kvesitadze about ongoing research and strain collections. On October 6, a field trip to representative natural resource sites brought the group to the Shiraki Valley, where the Panel observed 'hot soil' environments, the Kochebi salt lake and the Didnauri settlement and burial, a local archaeological excavation.

The Panel only visited one Georgian academic institution, the DIBB at the AUG, and all symposium research presentations were from that institution. The Panel's view of research in Georgia was limited to the DIBB, whose focus on applied research could have biased the Panel's impressions regarding basic research and education in Georgia. There were no site visits to hot springs, but instead the Panel visited a thermophilic soil ecosystem and a high salinity environment.

SECTION 1

COLLECTION OF MICROORGANISMS

The first day of the workshop began with a site visit to the AUG and the DIBB. The Institute is currently headed by Dr. Kvesitadze, the President of the National Academy of Sciences of Georgia. A repository of microorganisms based on Dr. Kvesitadze's original collection is routinely maintained at the DIBB. An exploration of this strain collection was one of the primary goals of this workshop.

The collection consists in part of:

- Lactic acid bacteria and yeast strains isolated from matsoni, a traditional Georgian fermented milk product similar to yogurt
- About 3000 mycelial fungi
- A collection of lytic phage strains that infect and kill plant pathogenic bacteria
- More than 2300 bacterial strains from various soil habitats in Georgia
- A collection of edible mushroom varieties

These organisms were classified on the basis of their morphology, physical properties and activity for selected enzymes using traditional determinative bacteriology methods performed at the DIBB and AUG. Many strains were only identified at the genus level, which is acceptable for initial biotechnology purposes, but is not sufficient for academic or publication purposes.

Most strains were selected for one or more of the following properties:

- Production of enzymes or secondary metabolites for biotechnology applications
- Heat stability
- Enzymes active over wide temperature, pH and salt ranges
- Organisms that detoxify oils, explosive compounds, organic compounds or pesticides

Some examples are the Basidiomycetes isolates Pleurolus ostreatus and Ganoderma lucidum, which produce polysaccharides, laccases and antioxidants. Other strains mediate lignin degradation at 27oC. Another focus of the collection was directed at microbes that produce biomass rich in highly nutritious proteins when grown on food wastes, such as orange and apple peels. This biomass product was

tested as a livestock feed additive where it was shown to be a good source of protein and to boost immunity, though no actual data as to the results of the animal feeding trials was shared or covered in detail. A number of strains were capable of oil, organic compound or high explosive TNT (2,4,6-Trinitrotoluene) degradation and exhibited detoxification activity in test soils. The Panel was concerned about the determination of bioremediation activity and indicated that field bioremediation controls along with laboratory controls are needed. Some of these controls were included in symposium presentations. However, insufficient comparison was given to published data for similar bioremediation scenarios, which is essential for understanding the value of Georgian strains vs. current gold standards. The use of strains with higher activity for bioremediation of polluted soils would improve the environment and potentially expand areas for agriculture in Georgia and in other countries. The AUG collections included many examples of strains with significant potential for various applications.

The Panel was unable to determine a clear academic purpose for the AUG collection as a whole. The Panel had the impression that the collection and isolation of strains was unfocused and represented the casting of a wide net to capture as many organisms as possible that could potentially be useful in current or future applications. There wasn't a sense that the collection was meant to represent the biodiversity of Georgia. Instead, it appeared to be a collection for applied research objectives.

The AUG collection did not have an available catalog, although the Panel was told that a catalog had previously existed. The numerous strains maintained at DIBB cannot be considered a formal collection of microorganisms by international standards without proper documentation describing strain identity, place of isolation, isolation source, date and conditions, the name of the person who isolated the strain, optimal growth conditions, biochemical and other characteristics, the name of the person who identified the strain, maintenance records and preservation procedures used. No company will touch a strain or its derivatives without a clear description of where it was isolated because of international treaties regarding natural resources. At a minimum, a modern strain collection requires sequencing ribosomal RNA genes for strain identification. Research studies are, when possible, a part of the every collection's activity. It would attract new collaborations and make important contributions to the understanding of the

microorganisms maintained if the most interesting strains are subjected to genomic analyses. The Panel appreciates the challenges associated with maintaining a catalog and performing sequence-based strain identification, including cost, equipment, supplies, computer database skills and personnel. However, the Panel believes that it would be very productive to analyze the currently collected strains and bring the collection up to international standards. These characterizations would maximize the potential of this collection as a valuable resource both within and outside of Georgia. Later sections of this report will discuss possible ways to achieve the goal of sequence-based strain identification. Once protocols for strain characterization are applied to collection strains, limited isolation of new strains would complement the existing collections.

RECOMMENDATIONS

The researchers and administrators may want to consider the following:

1 Bring the DIBB collection of microorganisms up to international standards. The guidelines for the establishment and operation of microorganism collections could be found on the website of the World Federation for Culture Collections (WFCC) at *www.wfcc.info/guidelines*.

2 Create a catalog of maintained and available microorganisms, and make this catalog publically available (e.g., publish on the world wide web). It would be most useful if specific information and knowledge about each strain would be included in the catalog. Collections are encouraged to adopt a format used by international and major regional collections. The WFCC World Data Centre for Microorganisms (WDCM) can provide helpful information and suggestions on appropriate levels of data management.

3 To gain a more structured knowledge of existing and future strains, it would be advisable to create a "pipeline" or "tool box" describing a step-by-step identification process for entry into the collection. For example, knowledge of the physicochemical characteristics of the site where the microorganism was isolated is crucial for determining strain bioremediation potential. Future research and commercialization would benefit by inclusion of as much information as possible in the catalog.

4 Create a template for a Material Transfer Agreement (MTA). This is a widely used practice for sending and receiving materials between collaborators, as well as between collections and researchers conducting both independent and collaborative research, and for setting the ground rules for publication. MTAs existing in certified collections of microorganisms, e.g. ATCC (American Type Culture Collection), could be provided upon request (contact email: *tvishniv@utk.edu*). The Georgian Technology Commercialization Office (TCO) discussed providing potential MTA documents, support, consulting service, and improving communication between research and business.

5 MTAs ensure that the interests of the collection and its researchers are protected. MTAs are also important for regulating relations between collections, academics and industry. They could facilitate the establishment of new collaborations, publications, applications and proposals.

SECTION 2

MICROBIAL DIVERSITY

Expanding our knowledge of Georgia's unique ecosystems and their microbial inhabitants is viewed by the Panel as a top priority for expanding the presence of Georgian research in global literature. The microbial diversity in any environment is generally rich and large enough to find microorganisms with useful or needed properties. Hot springs, thermal areas, salt ponds and soils are no different. During the site visit to the DIBB and AUG, a collection of bacterial and fungal isolates from specific Georgian environments (e.g., matsoni, vine grapes, rotten wood, soils) was presented to the Panel. Certainly the traditional determinative bacteriology performed at the DIBB and AUG, including the cultivation of environmental organisms in the laboratory, yields much information about microbial physiology, physical/chemical optima, metabolite production, etc. It can also inform us about the potential for particular strains to yield beneficial products such as antibiotics, enzymes and novel compounds for everything from cancer treatment to bioremediation of hydrocarbon and hazardous waste spills.

While this is all good and it can still be said that "to know them is to grow them," more knowledge can be gained from the exploration of total microbial diversity in any environment. Sequencing of the total genomic DNA (gDNA) from an environmental sample (described in more details in Section 3) allows identification of the majority of organisms present and can yield preliminary quantitative information. Moreover, this approach has the advantage of detecting both strains that cannot and can be cultivated without the laborious process of strain isolation. The extraction of gDNA follows well-established protocols and is performed in many laboratories. The cost of contract DNA sequencing is decreasing to the point of being possible for labs with limited budgets (see Section 3).

DNA sequencing approaches can also be valuable in more focused environments such as wine or matsoni. Georgian scientists have isolated many microorganisms considered to be main players in matsoni fermentation. This work can be extended by gDNA sequence analyses performed on different types of matsoni with the aim of finding the entire core microbiome characteristics for all types and the unique microbiome specific for each matsoni type. DNA sequence analysis could possibly identify interesting strains missed by standard culturing methods.

An important part of selective sample collection for the molecular analysis and ecology of microbial diversity comes from the "other" data of the site referred to as "metadata," which can then be used to more thoroughly interpret what a given microbial community is actually doing. Metadata includes, at a minimum, physicochemical parameters such as color, temperature, pH, Eh, acidity, salinity, alkalinity, total carbon and dissolved oxygen concentrations. More geochemistry such as dissolved gasses in water or metal ion and anion/cation concentrations further help to paint a picture of the environment. In addition, other areas of science could be tapped, particularly geology and even hydrology, to explain how the microbiota are affecting the environment as well as how the environment is affecting the microbes.

With the application of sequence-based microbiology, followed by integration of biodiversity and geochemistry, the researchers could move from questioning "who is there" to questioning "what are they doing" to "how are they doing it" to "why are they responding to the environment in a particular fashion". As listed, these questions are ranked from easiest to hardest in terms of cost, time and effort. The sampling of an environment is relatively simple, as is the geochemical analysis and DNA sequencing. What takes time is the interpretation of all of these data and the correlations that connect them, which are some of the most important aspects of the analyses. Bioinformatics is a rapidly growing field, and new tools are being developed everyday. Many bioinformatics tools are free and available on-line, e.g. the MG-RAST metagenomics analysis server (*metagenomics.anl.gov*), the NCBI BLAST server (*blast.ncbi.nlm.nih.gov/blast.cgi*), the Greengenes server (*greengenes.lbl.gov/cgi-bin/nph-index.cgi*) or the Mothur Project (*www.mothur.org*).

Engagement of students in interdisciplinary research would train them to become modern microbiologists who can work in the field, grow cultures from obtained samples, use many kinds of microscopy to visualize microbial cells, perform laboratory procedures to extract DNA and perform computational bioinformatics. With this skill set, new natural products are highly likely to be discovered, optimized and commercialized for the betterment of the people of Georgia.

RECOMMENDATIONS

1 Georgian microbiologists can better explore their natural resources by moving from additional strain isolation to a more comprehensive analysis of the biodiversity of each sampling site using a modern and integrated approach. Sampling many different kinds of environments at multiple time points will provide a fuller understanding of what is there, often pointing out important new strains that should be isolated for more detailed analysis.

2 Analysis of the full microbial diversity of specific environments will greatly enhance and extend the fundamental studies of Georgian microbiology that currently focuses on isolation of strains.

3 Establishing collaborations between Georgian microbiologists, molecular biologists, geologists, computational biologists and geochemists will help accomplish the goal of understanding broader microbial diversity in Georgian environments and ecosystems. International collaborations can also be considered.

4 Georgian microbiologists can take advantage of widely published and freely available literature that describes protocols, procedures and resources for modern microbial biodiversity studies.

5 The interdisciplinary education and cross-training of students (and more experienced specialists) in different fields, such as geochemists or computer scientists who understand microbes and vice versa, is critical for future microbiology research, and is worthy of being supported and encouraged on both a national and local level.

6 Georgian microbiologists can leverage their resources and gain technical assistance by partnering with academicians from around the world who are interested in better understanding biodiversity and the natural environment of Georgia.

SECTION 3

SEQUENCE DATA AND COMPUTATIONAL ANALYSIS

Ideally, targeted metagenomic sequencing in parallel with continued culturing should be a critical component of the goal of expanding the knowledge of Georgia's unique ecosystems and their microbial inhabitants. The DIBB and AUG collections include thousands of microorganisms identified typically at the level of genus. It is the Panel's opinion that these repositories would be greatly enhanced by the systematic inclusion of appropriate sequence data, namely bacterial 16S ribosomal RNA (rRNA) and fungal ITS regions (Internal Transcribed Sequences of ribosomal RNA genes). While the absence of this type of data was acknowledged by Georgian researchers, remediating the situation seemed to be viewed by them as unobtainable due in part to limitations in funding, equipment, knowledge base and personnel. It is the Panel's determination that the lack of sequence characterization and metadata presents non-trivial barriers to both international and internal collaborative efforts.

Current international microbiology research typically begins with environmental 16S rRNA gene/ITS surveys (amplicon sequencing) or environmental genome sequencing (metagenomics), both of which have become increasingly affordable. Typical costs associated with amplicon sequencing are now around 20-30 USD to access 100,000–200,000 sequence reads per sample, which should provide sufficient coverage to identify the dominant strain(s) present in any sample. However, these costs do not include bioinformatic analysis of the sequence data to identify strains. External facilities for DNA sequencing are available at universities and commercial sequencing centers around the world. While not the cheapest, Macrogen in South Korea (*www.macrogen.com*) is a very popular resource.

Given that cost is expected to be a major concern for both the targeted sequencing and environmental surveys, Georgian researchers could form collaborations with international researchers to mitigate these costs. Numerous avenues exist to pursue free or inexpensive external DNA sequencing. The Joint Genome Institute (JGI) is a resource that is currently utilized by many scientists worldwide and offers multiple proposal submission opportunities (*www.proposals.jgi.doe.gov*). The Workshop Initiation Process (WIP) application is available to apply for assistance, including, but not limited to, the Community Science Program (CSP) for large-scale and small-scale microbial

and metagenome sequencing (*jgi.doe.gov/collaborate-with-jgi/community-science-program*). The CSP large-scale and small-scale sequencing for genome and metagenome projects may be submitted at any time, although they are reviewed annually or every six months, respectively. In addition, the Bigelow Laboratory for Ocean Sciences offers the opportunity to send samples for free screening of uncultivable microorganisms, referred to as "Dark Matter" (contact email: *ebecraft@bigelow.org*). The biggest advantage of the Bigelow operation is that they perform bioinformatic analysis of rRNA genes and identify organisms in each sample for the submitting researcher. Sample preparation requirements are minimal (*www.bigelow.org*) and single cells determined to be of value to the further understanding of uncultured microorganisms will be sequenced with the requirement that all genomic data from these studies must be made public within six months in the JGI database. The possibility that this public disclosure may limit future intellectual property claims should be considered when determining the suitability of this free resource for samples of commercial importance.

One of the primary challenges to instituting broad-scale DNA sequencing is likely to be limitations in computational techniques and technologies typically used for the analysis of modern high-throughput sequencing data. The tools for processing large amounts of data often require computers with more processing power and random access memory (RAM) than typical in desktop computers. Another important component is familiarity with and knowledge of the wide variety of analysis software being developed on a daily basis. While this may be a daunting challenge, there are many tools designed for simple analysis and ease of use. Collaboration between biological researchers and computational scientists is common throughout the world to circumvent limitations in biological knowledge and computational techniques.

Some of the most convenient resources for training in computational analyses are international summer courses for training students in cutting-edge research techniques used in microbiology and geobiology. These programs are available to qualified international students, often at little or no cost. Two examples of long-running training programs are the International Geobiology Course (*www.dornsife.usc.edu/wrigley/geobiology*, *www.youtube.com/watch?v=38KC4QYRnJM*) and the Microbiology Diversity Course at the Marine Biological Laboratory in Woods Hole, MA (*www.mbl.edu/microbialdiversity*), which are

not only taught by leaders in microbiological research, but have produced new generations of leaders. Students participating in these courses receive training in next-generation sequencing technology and analysis. They also have the opportunity to meet and work alongside dozens of field-leading scientists. Utilizing these existing student-training programs is an effective strategy for training Georgian microbiologists and biotechnologists who will be able to participate on the international stage. Many international courses focus on training students in collaborative, interdisciplinary research, which this Panel has identified as a weakness among Georgian laboratories.

RECOMMENDATIONS

1 The value of the Georgian strain collections would be greatly enhanced by determining species identity through rRNA gene sequencing.

2 Establishing collaborations with international researchers (with appropriate MTAs) could provide avenues of low cost or free DNA sequencing to achieve amplicon and/or genome sequencing of repository strains and environmental samples.

3 Sequence-based microbiology research will benefit from establishing collaborations within or between Georgian universities/institutes that bring together biologists and computational experts.

4 Young researcher and student participation in established international training programs in microbial diversity, geobiology, DNA sequencing and bioinformatics will insure the future of Georgian microbiology and build on their strong foundation of microbiology research.

SECTION 4

THERMOPHILIC FIELD-SITE

Visiting hot springs was a major goal of this workshop along with evaluating Georgian thermophilic environments. The Panel had expected to visit hot springs, meet scientists who studied hot springs and see data specifically from hot springs. However, this did not occur, which was a missed opportunity both from a standpoint of future international collaborations and as a means to highlight the unique natural resources of Georgia. Visiting these sites is important even if not sampling. The flow rate, coloration, presence of filaments and other such factors can tell you a lot about a hot spring's geochemistry. The Panel found it difficult to determine the range and breadth of Georgian thermal environments on the Internet and recommends creating a public listing of the natural resources in the country. The Yellowstone National Park Research Coordination Network (*www.rcn.montana.edu*) created by the Montana State University is a good example of such a list of resources.

On the second day of the workshop the Panel traveled to the Shiraki Valley. During this visit it became clear to the Panel that the target "high temperature" site was the soils from which microbes were isolated, not the expected hot springs. The daytime air temperatures in the Shiraki Valley can reportedly reach up to 55°C (personal communication). Although the soil may reach temperatures typically associated with thermophiles during the day, the temperature significantly drops in the evening. As a result, these microbes are exposed to an extreme diurnal temperature variation, which is unique amongst the majority of thermophiles previously studied. Organisms isolated from these soils may reflect ones that actively grow only at the high daytime temperature or at

the low nighttime temperature or at both temperatures. It is possible that many of these soil bacteria are inactive in the environment during the hot summer season and are only active during cooler seasons or vice versa. The uniqueness of these microbes in a greater context requires further characterization of growth conditions and biodiversity by metagenome/amplicon analysis.

The Panel also visited Kochebi Lake in the Shiraki Valley, a hypersaline lake where during the summer the temperature of the shallow water and surrounding sediments covered with thick microbial mats reaches temperatures associated with thermophiles. This unique environment could be a productive location to study halophiles and thermophiles. It was the Panel's understanding that some of the isolates in the DIBB and AUG collections were from this lake. The Panel was disappointed that basic data about the lake, such as the pH or salt content, could not be provided by the Georgian scientists present on the site visit.

Another stop on the Shiraki Valley field trip was an archeological dig where the Didnauri settlement and burial (from 3800 BC) was being excavated. This was fascinating. The unearthed gravesite with numerous pieces of pottery was quite shallow. It was surprising to the Panel that the grave was less than a meter below the soil surface. In many regions soil accumulates over time, while in other regions soil is eroded. The fact that there was so little soil overlaying the archeological remains suggests that, if the dating of the site is correct, there must have been soil erosion occurring. The Panel was left with questions about how soil erosion might impact the soil microbial community composition and abundance over time.

During the scientific talks on day one, the Georgian scientists discussed the "black soils" and how unique these soils are. On the site visit, the Panel noted how a region that did not appear to receive much rainfall seemed to have very organic rich soils. Are these soils

particularly productive? In a time when drought and climate change are impacting global croplands, there may be a unique opportunity here to learn more about beneficial soil microbes and how to increase soil fertility. To this end, it is recommended that the sampling of the "black soils" for physicochemical and microbiological analyses be performed under non-selective conditions with numerous repeats and controls for determination of statistically significant data. Understanding the mechanisms responsible for these rich and productive soils is a unique opportunity for Georgian scientists to contribute to improved growth of agricultural crops.

RECOMMENDATIONS

1 Analysis and evaluation of Georgian environmental resources would be easier for Georgian and international scientists if a listing of the natural hot springs and other extreme environments were compiled and made publically available.

2 In light of the stress that changing climates are bringing to agriculture in Georgia and around the world, an analysis of physicochemical and microbiological properties of the "black soils" may provide insights into mechanisms responsible for these productive soils in a region with little rain.

3 A more comprehensive study of the microbiota in soils exposed to large diurnal temperature shifts could yield interesting data on the resident thermophiles and identify new organisms preferentially suited for growth or just survival over a large range of temperatures.

SECTION 5

POTENTIAL FOR COMMERCIALIZATION

The focus of each lab visited at the DIBB and AUG, and many of the symposium talks, was the numerous interesting biotechnology applications. However, it was hard to assess their stage of development because neither the Panel nor the presenters had time to drill down in detail on any single target. Among the promising applications were

- Improved probiotics
- Phage 'antimicrobials' to protect agricultural crops such as tomatoes from bacterial infection
- Strains for producing high value nutritional supplements for agricultural feed
- Bioremediation strains for toxic chemical agents, pesticides, oils and explosives
- Production of secondary metabolites and carotenoids
- Biofuels, ethanol production, plant degrading enzymes, ligninolytic enzymes, cellulases
- Strains expressing proteases, chitinases, laccases, endoglucanases, lectins and biosurfactants

Based on the current Georgian expertise in yogurts and matsoni, for example, *Lactobacillus* strains could contribute added value to current products by generating milk and fermented milk products that provide better nutrition or eliminate natural milk molecules known to cause digestive problems. Georgian scientists also described fungal strains that degraded food wastes to yield high protein biomass for supplementing livestock feed with positive preliminary results in livestock experiments. Examples were presented of strains that degrade oil, strains that degrade toxic organic compounds and explosives, and phage that protect tomatoes from specific bacterial infections.

For entry into the global market, commercial collaborators minimally require the following types of information:

- An informational package and/or database detailing research activities and assay information
- A signed MTA and a Confidential Invention Disclosure form
- A description of the ease of producing and purifying industrial scale reagent quantities
- Comparisons to gold standards
- Isolation information to ensure compliance with international natural resource standard practices

Georgian scientists presented intriguing preliminary data, but the Panel was unable to determine how stringent, detailed or high throughput their characterizations were. This type of information is essential for initiating industrial collaborations. A database of potential products would be beneficial for creating interest in Georgian products and establishing industrial liaisons based on detailed, proven product properties. Essential to judging any potential biotechnology application is a comparison to current gold standards and an independent analysis of the market to determine whether the targeted product can compete with the current state-of-the-art.

Industry is refocusing on natural products and natural strains because of increasing barriers to using Genetically Modified Organisms (GMOs). The avoidance of recombinant and genetically modified strains is a niche that Georgian scientists are poised to easily enter.

RECOMMENDATIONS

1 Resources might be better leveraged by choosing a more limited number of applications that either add value to existing products or focus on niches that the Georgians can exploit. To this end, an independent evaluation of market potential and product performance versus current gold standards should be performed on the most promising products. GITA may be helpful in setting up such an analysis.

2 Making international commercial connections would be expedited by generating a database of potential products that includes comparisons to gold standards, assay specificity, large-scale production capabilities and product characterizations. Development of a uniform template could help individual researchers or institutions to identify and gather the requisite information.

3 In light of the international backlash against genetically modified organisms, Georgian natural strains that produce commercially relevant products or activities are becoming more attractive than engineeredp strains and may provide a valuable commercial niche.

SECTION 6

STUDENT EDUCATION AND INVESTMENT IN RESEARCH / BIOTECHNOLOGY

Georgia's Innovation and Technology Agency (GITA) supports innovation, technologies, commercialization, and student startups. They develop collaborations between scientists affiliated with Georgian research institutions, which is needed in light of the TCO presentation documenting little collaboration among Georgian scientists. They also actively promote Georgian technology in the international arena. Having a technology agency that supports individual researchers or institutions should vastly improve lab to market progress and is especially useful now due to the many promising potential products currently under development in Georgia.

With regard to more basic research, the Panel thought that limited resources (both financial and physical) and limited training in modern sequence-based strain identification methods was preventing Georgian scientists from fully exploring and utilizing Georgia's biodiversity. The Panel highly encourages the inclusion of students in research as a vital component to developing a competitive pool of upcoming Georgian researchers.

Among many existing opportunities, potential funding options for building collaborations with US researchers and US student fellowship opportunities can be found at:

Partnerships for Enhanced Engagement in Research (PEER) program
www.nsf.gov/funding/pgm_summ.jsp?pims_id=504726

Partnerships for International Research and Education (PIRE) program
www.nsf.gov/funding/pgm_summ.jsp?pims_id=505038

International Research Experiences for Students (IRES) program
www.nsf.gov/funding/pgm_summ.jsp?pims_id=12831

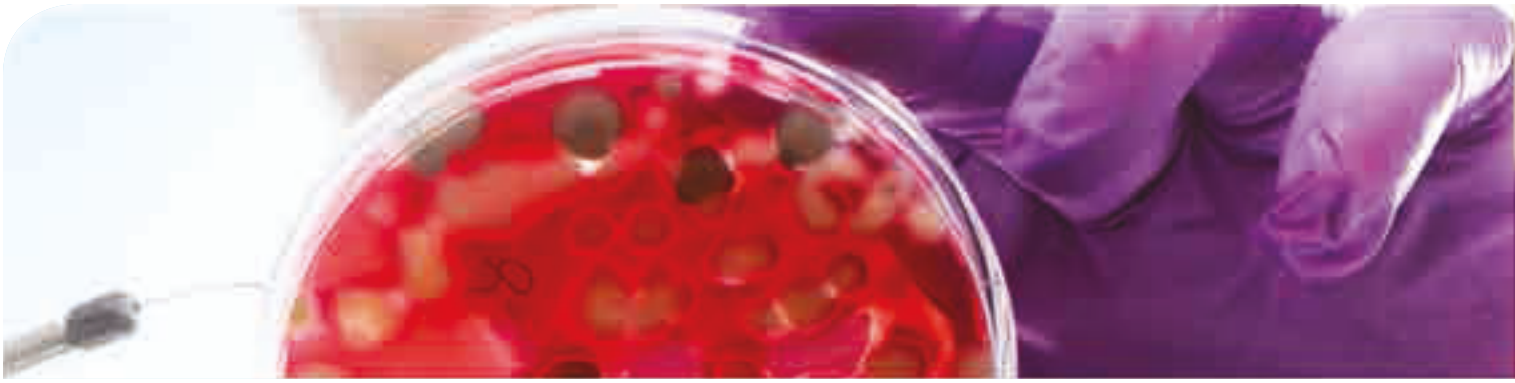
Newton's List at the CRDF website
newtonslist.crdfglobal.org/home

Fulbright Foreign Student Program
foreign.fulbrightonline.org

A blog about student fellowships
www.usnews.com/education/blogs/international-student-counsel/2013/10/29/find-fellowships-for-international-graduate-students

The International Geobiology Course
www.dornsife.usc.edu/wrigley/geobiology

The Microbiology Diversity Course at the Marine Biological Laboratory in Woods Hole, MA
www.mbl.edu/microbialdiversity



RECOMMENDATIONS

1 Active and strategic outreach to foster collaborations among Georgian scientists could jumpstart a move towards more modern and interdisciplinary microbiology programs without large increases in personnel to bring necessary new skills to existing groups.

2 Generation and distribution of template forms for MTAs, Confidentiality Agreements, strain collection database templates, collaboration agreements, etc. would be financially prudent rather than having each laboratory create their own documents.

3 Generation and distribution of information regarding resources and funding opportunities (proposals to international research competitions, low cost sequencing resources, training and exchange opportunities, etc.) both in Georgia and abroad would stimulate participation, attract talented people into a science career and advance science as a whole in Georgia.

4 The Panel wondered if GITA considers itself to be the appropriate agency to lobby for increased salaries and funding for all levels of Georgian scientists to attract the best and brightest Georgians into science careers and to maintain the current group of excellent scientists.

5 Supporting the education of students in the interdisciplinary fields comprising modern microbiology will be extremely productive and beneficial for the people of Georgia.

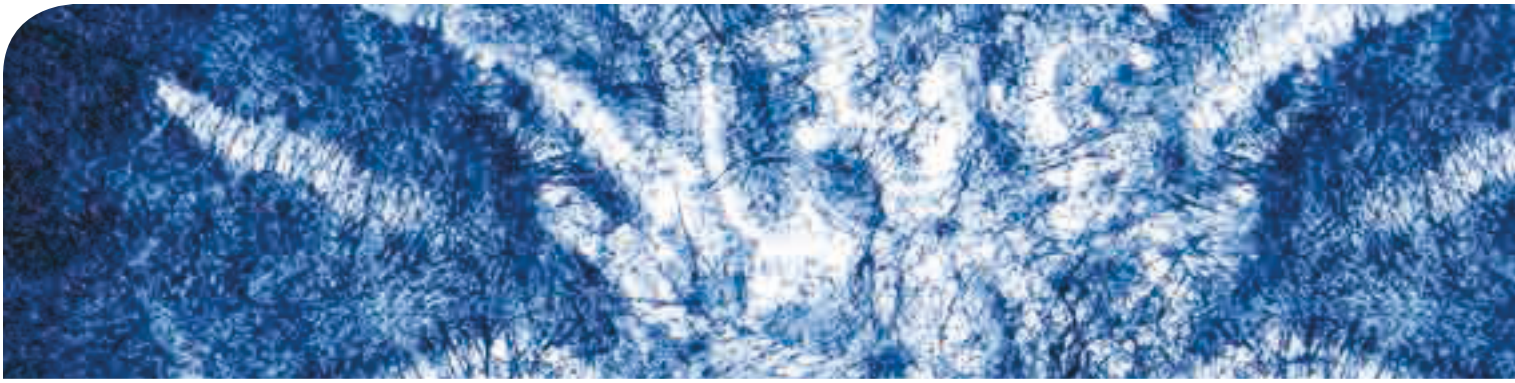
6 Inclusion of students in laboratory settings early in their careers will stimulate them to pursue research careers and provide better-trained personnel.

SECTION 7

CULTURAL COMPONENT OF THE VISIT

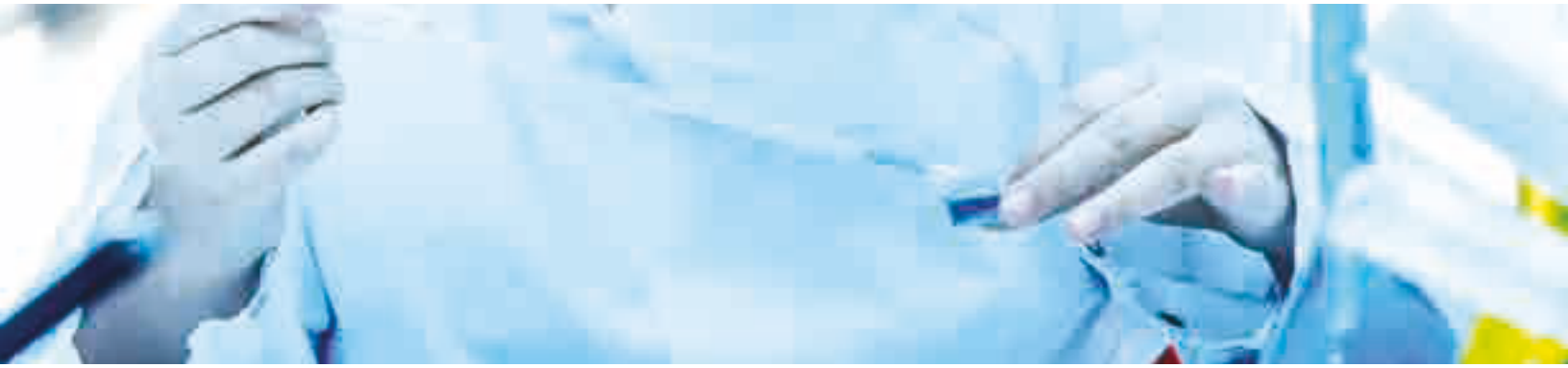
The country of Georgia welcomed the Panel with open arms. The people of Georgia were overwhelmingly hospitable. They were proud that they were being represented on a global scale by this workshop and it was clear that they did whatever they could to make the Panel feel welcomed in their country. It was obvious that they are a very proud people - proud in their research, proud in their food, and proud to show the Panel what their country has to offer. The Panel appreciated visiting cultural and historic sites in Georgia, and experiencing traditional meals and yummy Khachapuri cheese pies.

Overall, the Panel thought that the country of Georgia is a beautiful area with much potential, especially if Georgian researchers in microbiology are able to capitalize on the strengths in their region. The Panel was glad to have gotten the chance to explore the countryside and dine with locals, as it was a great way to become familiar with the state of the country and its people. This was a part of the world that most of the Panel had not thought to visit, but afterwards, were thankful to have gotten the opportunity.



OVERALL PANEL RECOMMENDATIONS FOR GEORGIA

1 In order to be competitive on the international stage, the Georgian collection of microorganisms needs to be brought up to international culture collection standards.



2 The modern microbiologist requires knowledge of many different specialties and it would therefore be beneficial to foster further training at all levels through local and international courses, visiting scientist exchanges to and from Georgia or between Georgian institutions/ departments, and new educational curricula that emphasize interdepartmental training in modern microbiology and microbial diversity methods.

3 International and local collaborations will enhance and expedite building Georgian research capacity at every level.

4 In times of limited resources, it is necessary to focus on areas that represent unique Georgian niches and build on existing strengths. To this end, further meetings/workshops with industrial scientists, marketing and business representatives could be valuable to determine which applied areas are most likely to achieve commercial success in the near term.

5 A governmental repository of template documents to serve as starting points for commercial and academic exchange agreements would be a cost effective way of protecting Georgian resources and encouraging corporations, funding agencies, strain collections and academic researchers to invest in Georgian science. These documents facilitate interaction by clearly defining each party's role and responsibility, and they are considered a necessary first step by most international organizations.

ARMENIA

WORKSHOP

YEREVAN

OCTOBER
8-10
2015

THE WORKSHOP IN ARMENIA

The Panel was driven by coach from Tbilisi to Yerevan on the afternoon of October 7, 2015 and returned to the US on October 11, 2015. The Armenian symposium took place in the conference hall of the ANI Plaza Hotel in Yerevan on October 8, 2015. The US participants and over 40 Armenian scientists including 15 students from different Armenian institutions participated in plenary sessions, poster sessions and discussions. Opening remarks were delivered by Samvel Haroutiunian (Chairman of the State Committee of Science of the Ministry of Education and Science) and Ashot S. Saghyan (National Academy of Sciences Republic of Armenia (RA), and Director of the Scientific and Production Center Armbiotechnology). The symposium presentation by Professor Armen Trchounian (National Academy of Sciences RA, and Head of the Department of Microbiology, Microbe and Plant Biotechnology at Yerevan State University) provided an excellent overview of education programs at YSU. The agenda for the Armenian workshop with listings of speaker names and presentation titles, plus listings of site visits and cultural events can be found in Appendix 2.

Prior to the symposium on October 8th, the Panel and NSF Program Directors visited the Scientific and Production Center Armbiotechnology (Armbiotech), where they were shown strain collections, biotechnology applications and chemical synthesis projects, among other subjects. The Panel was privileged to meet Dr. Evrik Afrikian, Academician of the National Academy of Sciences of the RA and scientific lead of Armbiotech, who is an icon in the field of microbiology, making seminal contributions to our understanding of soil bacteria and the use of bacteria as insecticides. On October 9th, the Panel and NSF Program Directors visited Yerevan State University (YSU) and a thermophilic spring in Hanqavan. The Panel members met students, professors and research staff at YSU, where they informally discussed research, strain collections and student training.

The Panel visited institutions devoted to both applied and basic research, giving them a broader view of Armenian science despite meeting with only a limited number of research groups. That said, this report still reflects very short discussions with a small number of Armenian scientists and may not fully reflect the state of microbiology or biotechnology research in Armenia.

SECTION 1

COLLECTION OF MICROORGANISMS

Armenia is home to a vast diversity number of resident microbes because of the extreme ecological conditions found in the Caucasus and the diverse environments present throughout the country. Armenian microbiologists have studied these microorganisms for over half a century, isolating strains of basic and applied interest. They have gained international recognition through insightful publications and successful commercialization projects. As a result, Armenia has a tremendously valuable resource comprised, in part, of a huge collection of microbial strains (>15,000) and the scientists who study them. In 1993, the Microbial Depository Center was established in the city of Abovyan (near Yerevan) by the Armenian National Academy of Sciences, followed in 2006 by the Joint Center of Microbiology and Microbial Depository, and in 2010 by Armbiotech. This collection is part of the World Federation of Culture Collections. Almost 16% of the strains are *Bacillus*, while others belong to mesophilic and thermophilic bacterial strains, fungal strains isolated from synthetic polymeric materials, entemopathogenic strains that attack insects and phytopathogenic strains that attack plants, such as unwanted weeds.

The Panel found that strain collections were maintained at a high level. During their site visit to Armbiotech on October 8th, the Panel was shown printed copies of collection databases, including a 2005 Atlas in English. The Panel observed first-rate storage facilities such as the one for the *Bacillus thuringiensis* strain

collection (>5000) started by Professor Afrikian in 1990, which was maintained at a high level with both cryopreservation and lyophilization. The isolation and cataloging of hot spring isolates at YSU, observed during the site visit there on October 9th, was also performed at a high level with new strains continually being added. Perhaps the only major concern the Panel had regarding storage of the microbial collections was the absence of duplicate storage facilities in a separate building to prevent accidental loss due to equipment malfunction or a catastrophic building failure, especially of type strains and principle isolates.

Discussions between the Panel members and Armenian scientists did not cover depositing strains in independent collections and the need to protect these valuable resources, so the following policies may already be in practice in Armenia. It is a generally recognized requirement that type strains be deposited into two separate collections. Many publications and patents require deposition of strains into accredited culture collections. Moreover, well-described isolates deposited in internationally accessible culture collections maximize sharing of strains as well as stimulating old and new collaborations. However, adequate legal protection should be provided when depositing strains in local, national or international culture collections to prevent any misuse or exploitation of isolates, especially those strains obtained from locations within Armenia. Standard agreements can be put into place to protect future commercial use if some profit sharing is to be realized and to maintain intellectual property rights. For example, many repositories, such as the ATCC (American Type Culture Collection), protect intellectual property by allowing deposition of strains without public access.

It would be beneficial for internal, international and commercial purposes if a National Armenian Collection of Microorganisms were established to unify the current collections present at different institutions. A national database with a single template for submission would insure a uniform quality of minimal metadata and preservation conditions, and could meet the international requirement that type strains be deposited in two collections (the national collection and the university/institute collection) without having to deposit strains outside of Armenia. If financial concerns limit establishing a new national repository, the Panel recommends converting the existing Armbiotech culture collection into a national repository that solicits deposition of strains from other collections and institutions throughout Armenia. This would of course require further financial support.

Armenia has a strong history of general and applied microbiology, with many publications and successful commercial enterprises. Continued government and institutional support for isolation of new strains and maintaining the current collections is essential for the future development of Armbiotech, allowing it to continue to receive international recognition and to continue to improve this valuable resource for Armenia. The same is true for university collections, such as the one at YSU.

RECOMMENDATIONS

1 Support and establishment of a National Armenian Collection of Microorganisms combining the current Armbiotech strain collection and the smaller strain collections at various institutions in Armenia would protect and enhance the academic and commercial value of this excellent resource.

2 Backup storage facilities within each institution or by deposition in another strain collection will protect valuable and type strains from accidental loss.

3 Maintenance of the complete catalog of the Armenian collection of microorganisms is essential for classification as an international level repository and to facilitate use of strains.

4 Maintenance of the strain catalog could be simplified by creating a “pipeline” or “tool box” with a step-by-step identification process for entry into the collection that would consist of the current required strain information and other data deemed important for strain characterization.

5 If not already available, a template for a strain Material Transfer Agreement (MTA) would protect intellectual property rights of this valuable Armenian resource and simplify collaborative use of strains.

6 Support for continued collection of new isolates and characterization of current isolates will maintain the current high profile of Armenian microbiology in basic and applied realms.

SECTION 2

MICROBIAL DIVERSITY

Every environment is typically rich in microbial diversity, including hot springs and thermal areas. Although thermophiles make up only a small portion of the Armenian culture collections, at least 1000 thermophilic strains have been isolated and deposited. Certainly the traditional determinative bacteriology performed in Armenia, including the cultivation of environmental organisms in the laboratory, yields much information about microbial physiology, physical/chemical optima, metabolite production, etc. It can also inform us about the potential for particular strains to yield beneficial products such as antibiotics, enzymes and novel compounds for everything from cancer treatment to bioremediation of hydrocarbon and hazardous waste spills to bio-pesticides that attack larval or adult insects. While this is all good and it can still be said that "to know them is to grow them," more knowledge can be gained from the exploration of total microbial diversity in any environment. Sequencing of the total genomic DNA (gDNA) from an environmental sample (described in more detail in Section 3) allows identification of the majority of organisms present and can yield preliminary quantitative information. Moreover, the latter approach has the advantage of detecting both strains that cannot and can be cultivated without the laborious process of strain isolation. DNA sequencing approaches can also be valuable in more focused environments such as wine, spirits or Armenian fermented milk products such as NARINE and Matsun. The extraction of gDNA follows well-established protocols and is performed in many laboratories, including at YSU. The cost of contract DNA sequencing is decreasing to the point of being possible for labs with limited budgets (see Section 3).

An important part of selective sample collection for the molecular analysis and ecology of microbial diversity comes from the "other" data of the site referred to as metadata, which can then be used to more thoroughly interpret what a given microbial community is actually doing. Metadata includes, at a minimum, physical parameters such as temperature, pH, Eh, salinity, acidity, alkalinity, and dissolved oxygen concentration. More geochemistry

such as dissolved gasses in water or metal ion and anion/cation concentrations further help to paint a picture of the environment. In addition, other areas of science could be tapped, particularly geology and even hydrology, to explain how the microbiota are affecting the environment as well as how the environment is affecting the microbes. Symposium presentations indicate that Armenian scientists are already focusing on such collaborative, interdisciplinary approaches.

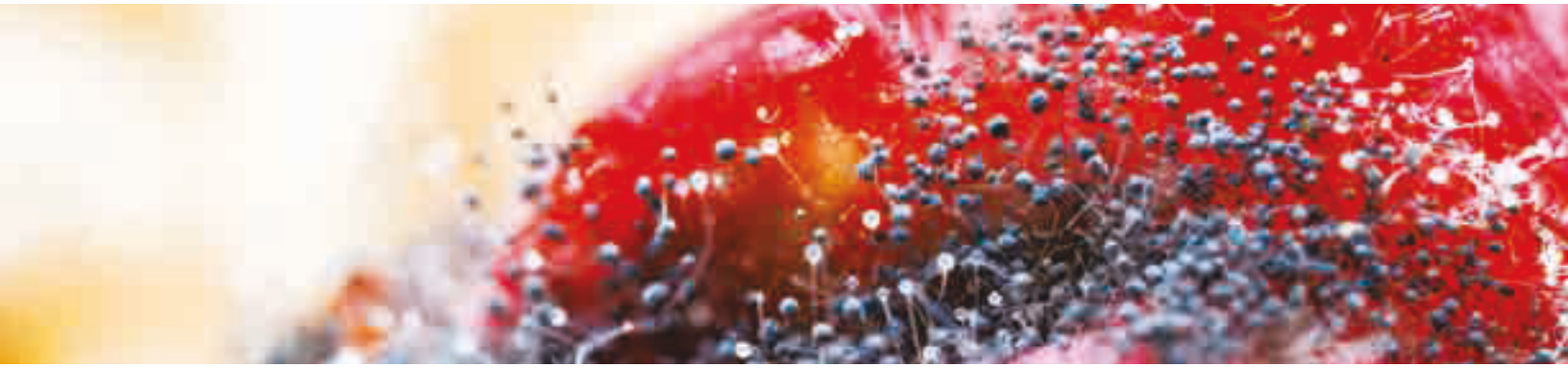
With the application of sequence-based microbiology, followed by integration of biodiversity and geochemistry, the researchers could move from questioning "who is there" to questioning "what are they doing" to "how are they doing it" to "why are they responding to the environment in a particular fashion". As listed, these questions are ranked from easiest to hardest in terms of cost, time and effort. The sampling of an environment is relatively simple, as is the geochemical analysis and DNA sequencing. What takes time is the interpretation of all of these data and the correlations that connect them, which are some of the most important aspects of the analysis. Bioinformatics is a rapidly growing field, and new tools are being developed everyday. Many bioinformatics tools are free and available on-line, e.g. the MG-RAST metagenomics analysis server (*metagenomics.anl.gov*), the NCBI BLAST server (*blast.ncbi.nlm.nih.gov/Blast.cgi*), the Greengenes server (*greengenes.lbl.gov/cgi-bin/nph-index.cgi*) or the Mothur project (*www.mothur.org*).

The microbial ecology researchers of Armenia, particularly Hovik Panosyan who the Panel visited at YSU, are engaging in all aspects of modern microbial diversity described above to better understand both the native microbial ecosystems (e.g., the microbiota of hot springs) and what kinds of natural products can be generated from this biodiversity. Another example is the Geomicrobiology laboratory at Armbiotech that studies chemolithotrophic bacteria integrating microbiology, geobiology, and geochemistry disciplines.

With collaborations already established in multiple countries (Germany, Norway, Georgia and the United States), Armenian researchers are conducting state-of-the-art research, presenting posters and talks at scientific meetings, and publishing their work in high-impact journals.

RECOMMENDATIONS

1 The Panel was impressed with the state of modern microbiology research and education in Armenia, and recommends expanded governmental support of these extremely strong programs, which have garnered international attention and produced numerous commercially important findings.



2 The education and cross-training of students (and more experienced specialists) in different fields, such as geochemists or computer scientists who understand microbes and vice versa, is critical for future microbiology research, and is worthy of being supported and encouraged on both a national and local level.

3 The Panel believes that the amount of DNA-based microbial diversity methods currently being practiced warrants the establishment of a National Core Facility in Armenia to perform PCR amplicon identification and DNA sequencing (Sanger and Illumina). This will facilitate genomics and metagenomics research in Armenia, especially research conducted by young scientists, and will strengthen the country's position in the academic arena and biotechnology marketplace.

SECTION 3

SEQUENCE DATA AND COMPUTATIONAL ANALYSIS

The following is a general overview of the utilization of sequencing, –omics technologies and bioinformatics techniques currently in practice in Armenia as ascertained during the symposium and by the Panel's site visits to Armbiotech and YSU. In general, students were engaged in lab activities, presented posters professionally, and were well educated in diverse sequencing platforms and the interpretation of sequence data. Senior scientists were fully aware of the importance of sequence data for publishing quality science that can be utilized worldwide. In this Panel's evaluation, these scientists were very capable of using advanced –omics technologies and datasets.

More specifically, the senior scientists at Armbiotech appreciated the importance of genetic identification and routinely performed PCR typing of isolates using species-specific primers. Cultured isolates that were of commercial interest were identified and thoroughly cataloged. Multiple professors at YSU used both Sanger DNA sequencing technologies to identify isolates and high-throughput ribosomal RNA (rRNA) genotyping of environmental samples to better understand the diversity of microbial communities, including sites of potential world-wide interest such as mines and hot springs. Additionally, targeted gene sequencing was utilized to examine co-evolution of industrially important enzymes from cultured isolates (e.g. *Bacillus stains*). Metagenomic and transcriptomic data were absent or very limited, and computational capabilities observed by the Panel at the institutions mentioned above were minimal. However, it is the opinion of the Panel that limited resources were the major barrier to obtaining and analyzing various meta-omics datasets. More importantly, the Armenian scientists were fully aware of this limitation. To remedy it, they are actively seeking support from international organizations and have developed multiple international collaborations, including ones with American scientists. These efforts have helped purchase modern laboratory equipment and pay for large-scale sequencing projects abroad, which have resulted in numerous published papers in respected journals.

Even in the absence of collaboration, multiple avenues exist to pursue free or inexpensive DNA sequencing to expand the datasets available for analysis. The Joint Genome Institute (JGI) is a resource that is currently utilized by many scientists worldwide and offers multiple proposal submission opportunities (*www.proposals.jgi.doe.gov*). The Workshop Initiation Process (WIP)

application is available to apply for assistance, including, but not limited to, the Community Science Program (CSP) for large-scale and small-scale microbial and metagenome sequencing. CSP large-scale and small-scale sequencing for genome and metagenome projects may be submitted at any time, although they are reviewed annually or every six months, respectively. In addition, the Bigelow Laboratory for Ocean Sciences offers the opportunity to send samples for free screening of uncultivable microorganisms, referred to as "Dark Matter" (contact email: *ebecraft@bigelow.org*). The biggest advantage of the Bigelow operation is that they perform bioinformatic analysis of rRNA genes and identify organisms in each sample for the submitting researcher. Sample preparation requirements are minimal (*www.bigelow.org*) and single cells determined to be of value to the further understanding of uncultured microorganisms will be sequenced with the requirement that all genomic data from these studies are made public within six months in the JGI database. The possibility that this public disclosure may limit future intellectual property claims should be considered when determining the suitability of this free resource for samples of commercial importance.

One of the primary challenges to instituting broad-scale DNA sequencing is likely to be limitations in computational techniques and technologies typically used for the analysis of modern high-throughput sequencing data. The tools for processing large amounts of data often require computers with more processing power and random access memory (RAM) than typical in desktop computers. Another important component is familiarity with and knowledge of the wide variety of analysis software being developed on a daily basis. While this may be a daunting challenge, there are many tools designed for simple analysis and ease of use. Collaboration between biological researchers and computational scientists is common throughout the world to circumvent limitations in biological knowledge and computational techniques.

Some of the most convenient resources for training in computational analyses are international summer courses for training students in cutting-edge research techniques used in microbiology and geobiology. These programs are available to qualified international students, often at little or no cost. Two examples of long-running training programs are the International Geobiology Course (*www.dornsife.usc.edu/wrigley/geobiology* and *www.youtube.com/watch?v=38KC4QYRnJM*) and the Microbiology Diversity Course at the Marine Biological Laboratory in Woods Hole, MA (*www.mbl.edu/microbialdiversity*), which are not only taught by leaders in microbiological research, but have produced new generations of leaders. Students participating in these courses receive training in next-generation sequencing technology and analysis. They

also have the opportunity to meet and work alongside dozens of field-leading scientists. Many of the international courses focus on training students in collaborative, interdisciplinary research. Utilizing these existing student-training programs is an effective strategy for training Armenian microbiologists and biotechnologists who will be able to participate on the international stage. While this type of research is already being actively carried out by some Armenian scientists, these courses could bring the latest methods back to Armenia and also provide mechanisms for students to make international contacts that could stimulate international interest in Armenian research and microbiology/ biotechnology resources.

RECOMMENDATIONS

1 Establishing collaborations with international researchers (with appropriate MTAs) could provide avenues of low cost or free DNA sequencing to achieve amplicon and/or genome/metagenome sequencing of collection strains and environmental samples.

2 Sequence-based microbiology research will benefit from establishing a national core facility in Armenia for low cost DNA sequencing and amplicon analysis.

3 Supporting the exchange of students and young scientists within Armenia and internationally, including participating in internationally recognized training courses, is encouraged.

SECTION 4

THERMOPHILIC FIELD-SITE

On October 8th, the US experts visited Armbiotech. Dr. Ashot S. Saghyan gave an overview of the center, which uses biotechnological processes for the isolation and purification of bioactive compounds. This center also develops new technologies for amino acid synthesis using low cost substrates and simultaneously increases the level of amino acid activity. Armbiotech is looking for a way to enter the international market with the ecologically safe production of NARINE and other biologically active substances. Dr. Vigen Goginyan then described Armbiotech's collection of microorganisms that includes about 20,000 strains, which are stored lyophilized in closed glass vials. Almost 16% of the strains are *Bacillus*, others are mesophilic and thermophilic bacterial strains, fungal strains isolated from synthetic polymeric materials, entemopathogenic and phytopathogenic strains. All strains maintained in the collection are documented in a catalog. The group visited the Centre of Microbiology and Microbial Depository and met Professor Evrik Afrikian, Academician of NAS RA and former Director of the Center, as well as other research faculty, staff and students.

October 9th started with a visit to YSU, where the Panel saw a collection of plant callus cultures, lactic acid bacteria isolated from dairy products, and 50 strains isolated from honeybee gut. YSU scientists are developing approaches for food safety using anti-fungal substances to prevent food spoiling.

The group then visited a handful of scientific and cultural sites outside of Yerevan. Of most relevance to the science of the workshop, the Panel visited

Hanqavan thermal spring, which is a drilled geothermal well (400 meters depth). Drilling enhanced the hot water flow for spring commercialization. In addition to this spring, the scientific talks at the symposium made it clear that there are many actively studied springs in Armenia. The temperature of these springs is such that they predominantly contain mesophilic bacteria and a few thermophiles. It is unfortunate that many of the natural springs were destroyed or are in regions where there are ongoing land disputes.

The US delegation noted that the Hanqavan spring was drilled to enhance the flow of a natural spring and wondered how many of the other hot springs in Armenia were also modified. In the United States, regulations are now limiting some avenues of experimentation, especially manipulation of flow at natural hot springs. The Armenians are therefore in a unique position to use their springs as field-based laboratories, since barriers to manipulating the hot springs may be absent, especially when the spring has already been modified by drilling or other interventions. For example, it would be interesting to study the natural succession of microbes over time along a thermal or chemical gradient away from a thermal spring source whose flow has been experimentally modified, which would allow examination of the sequential processes occurring when flow rates or the stream path change.

Armenia also has many regions where cold and hot springs exists in close proximity. To date, there have not been studies to see if these springs have similar or different microbial community or geochemical compositions. For example, do microorganisms in these springs contain similar enzymes? Do microbes have and express the same genes in different environmental conditions? These may be interesting topics for future study.

RECOMMENDATIONS

1 Analysis and evaluation of Armenian environmental resources would be easier for Armenian and international scientists if a listing of the natural hot springs and other extreme environments were compiled and made publically available. An example of such a list of natural resources is the Yellowstone National Park Research Coordination Network (*www.rcn.montana.edu*) created by the Montana State University.

2 Continued support of the institutions visited by the Panel should be encouraged, especially for training of young faculty and students.

3 Several unique properties associated with Armenian springs make them quite interesting targets for investigation of microbial biodiversity that could be pursued through international collaborations.

SECTION 5

POTENTIAL FOR COMMERCIALIZATION

Please note that biomedical applications will be discussed in Section 6.

The Armenian scientists that the Panel met are very active researchers with an eye for biotechnology applications. They have a history of diverse and active agreements with international and local companies, although some of these agreements were lost after their separation from the Soviet Union because, in part, Armenia lost access to manufacturing facilities in the former Soviet Union. They have already begun to make new connections to replace lost facilities and to move to more modern, cost effective products. However, it was hard to assess their stage of development because neither the Panel nor the presenters had time to drill down in detail on any potential product.

Among the promising applications are:

- Strains for improved probiotics, especially strains from NARINE
- Strains producing entomopathogenic reagents to kill adult and larval stage insects that are agricultural or health pests
- Phytopathogenic bacterial strains that kill weeds and other unwanted plants
- Bioremediation strains
- Production of secondary metabolites, sugars, carbohydrates and carotenoids
- Biofuels, ethanol production, plant degrading enzymes and cellulases
- Strains naturally expressing enzymes for biotechnology or antimicrobial agents
- Chemical synthesis of unnatural, modified or chiral-specific amino acids
- Production of biofertilizers (Azozeovit-1) based on free-living nitrogen-fixing bacteria
- Generation of shuttle vectors and recombinant strains for synthesis of commercially important reagents and enzymes
- Biological based mining of minerals using chemolithotrophic bacteria

Armbiotech presently has cooperative programs with Bizon-1 JSC and NektarBonus JSC for the production of healthy plants, teas, fruits and other consumables. At present, synthetic amino acids are sold to Acros Organics (Belgium) and Iris Biotech GmbH (Germany), while biosynthetic amino acids are sold to Degussa AG-Rexim (Germany/France) and Evonik-Rexi (Germany). Armbiotech also produces the antimicrobial preparation AMP-1 for veterinary uses including

gastrointestinal infections (Patents of RA N°. 1473-A2, 1723-A2). Armbiotech scientists have developed technologies for large-scale production of the ecologically safe biofertilizer Azozeovit-1. Technological approaches centered on bacterial leaching of metals for extraction of valuable, non-ferrous and rare metals from difficult-to-treat concentrates have been developed based on a large culture collection of chemolithotrophic bacteria.

Armbiotech and Professor Afrikian have made seminal contributions to the use of *Bacillus thuringiensis* strains to kill various insect pests. These novel bacterial insecticide preparations are continually improving, adding features such as phage resistance, which improves strain viability in natural environments. They have been used worldwide to control Lepidoptera, including larval stages, and insects that transmit disease (see Section 6). Armenia could benefit from exporting these bacterial insecticide preparations. They have also established PCR-based methods for molecular genotyping of entomopathogenic bacilli.

The health benefits of NARINE, a fermented milk product traditionally produced in Armenia, are described in Section 6. The window for new probiotic products may not be as open in the near future as it is now. Because of competition, we recommend that the government and/or industry financially support Armenian scientists to quickly develop dry product versions of NARINE to facilitate international sales. The Armenians could also capitalize upon recent and incoming results from human microbiome projects for a wider distribution of NARINE.

A true evaluation of commercial potential was not possible because of time constraints, which generally limited presentations to little more than a listing of products with a brief description of their merits. Although Armenian scientists presented intriguing preliminary data, the Panel was unable to determine how stringent, detailed or high throughput their characterizations were. This type of information is essential for initiating industrial collaborations.

For entry into the global market, commercial collaborators minimally require the following types of information:

- An informational package and/or database detailing research activities and assay information

- A signed MTA and a Confidential Invention Disclosure form
- A description of the ease of producing and purifying industrial scale reagent quantities
- Comparisons to gold standards
- Isolation information to ensure compliance with international natural resource standard practices

A database of this information would be very beneficial for creating interest in Armenian products and establishing industrial liaisons based on detailed, proven product properties. Essential to judging any potential biotechnology application is a comparison to current gold standards and an independent analysis of the market to determine whether the targeted product can compete with the current state-of-the-art.

RECOMMENDATIONS

1 Resources might be better leveraged by choosing a more limited number of applications that either add value to existing products or focus on niches that the Armenians can exploit. To this end, an independent evaluation of market potential and product performance versus current gold standards should be performed on the most promising products.

2 Making international commercial connections would be expedited by generating a database of potential products that includes comparisons to gold standards, assay specificity, large-scale production capabilities and product characterizations. A uniform template could help individual researchers or institutions to identify and gather the requisite information.

3 A national innovation and technology agency or organization may be helpful in setting up a database of applied research, initiating analyses of commercial potential and establishing commercial contacts.

4 The current world interest in probiotics makes research to convert NARINE to a solid format very attractive, especially if it can be gotten to market in a short time. This would be expedited by greater financial support.

5 Continued support of current commercial products (such as entomopathogenic agents, NARINE, high value amino acid preparations, etc.) and future products (such as biofertilizers or antimicrobials) will benefit the Armenian people.

SECTION 6

BIOMEDICAL

During the symposium and site visits to Armbiotech and YSU, the Panel found that the Armenians have interesting biomedical research data and products with potential for successful collaboration and commercialization. The laboratory of Dr. Saakyan (YSU) has cultured callus cells of endemic plants that have known antibacterial, antioxidant and anticancer activities. These medicinal plants are currently used in traditional medicine due to their anti-inflammatory, anti-malarial or hemostatic properties. The Armenian scientists were able to produce callus cultures of these plants without losing these pharmaceutical features, which allows experimentation under more rigorous standardized conditions with greater reproducibility, making them potentially interesting for international collaborations.

Armbiotech and Professor Afrikian have pioneered the use of bacterial larvicide preparations based on their vast collection of *Bacillus thuringiensis* strains. These preparations have been used to target mosquito and blackfly larvae that transmit diseases to humans and livestock, including *Aedes, Culex Anopheles* and *Uranotaenia* mosquitoes, and blackflies of the family *Simuliidae*. These insects transmit malaria and River Blindness, the leading cause of infectious blindness in the world. During the time of the former Soviet Union, ~300 thousand tons of these entomopathogenic agents were produced per year.

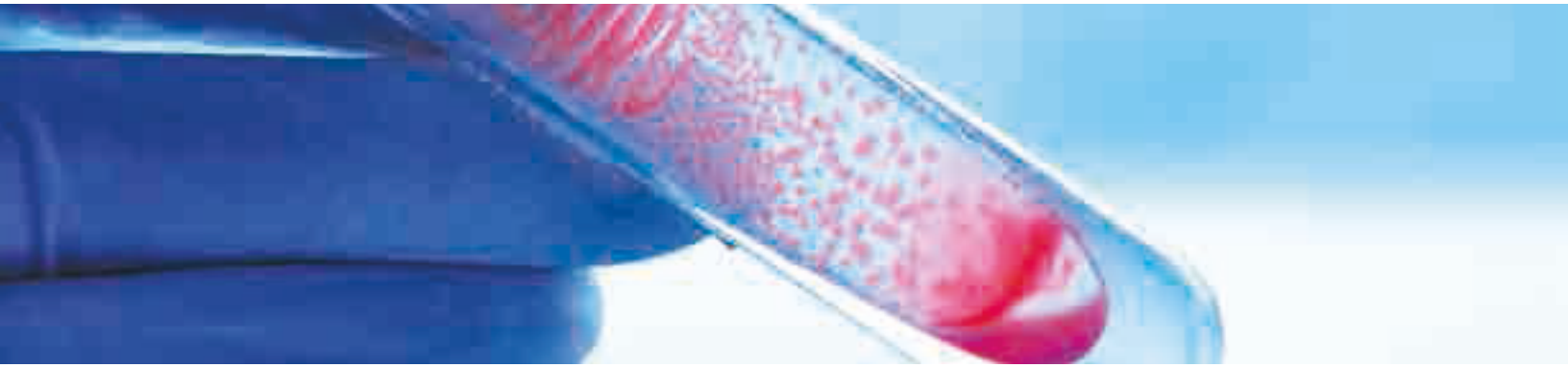
The research group of Dr. Afrikian initially studied *Bacillus thuringiensis* isolates for their ability to kill adult insects and their larvae. Recent studies in this lab and elsewhere have shown that crystal

protein formations containing parasporins from *Bacillus thuringiensis* isolates and other bacteria have anticancer activity. Armbiotech researchers have the advantage of possessing thousands of *Bacillus* strains to test for anticancer activity. Many of these strains have been tested on cultured carcinoma cells for cancerolytic properties. Several of the most effective strains are now under collaborative analysis with researchers in Malaysia, New Zealand and Australia. These findings are potentially interesting for collaboration in the basic science field worldwide, as well as in more applied studies.

NARINE is another product that Armenians are proud of. This probiotic dairy product has been on the local market since 1963 and is based on milk fermentation by specific lactic acid bacteria, *Lactbacillus acidophilus* INMIA B-9602, isolated and studied by Armenian scientists. NARINE has won recognition as a therapeutic and preventive agent in various disorders of gastrointestinal tract and is approved for this application by the World Health Organization. However, it is problematic to sell it internationally because of its short shelf life (3 days). To alleviate this problem and expand commercialization, they are currently selling a technology license and developing solid forms of NARINE, which could be used in capsules or recovered from capsules. It should be noted that NARINE, traditionally used as a product for babies, has more potential on the market as a dietary supplement for recovery of intestinal microbiota in patients undergoing chemotherapy and long-term antibiotic treatments, a prophylactic treatment for travelers or for people with intestinal inflammations. It could be interesting for microbiologists or infectious disease specialists to use NARINE in studies on manipulating the human microbiome for better digestive health.

RECOMMENDATIONS

1 The large Armenian culture collections with concentrations of different groups of microorganisms has given Armenian scientists a unique resource to develop anticancer therapeutics, providing another example of the value of these collections and reinforcing the need to maintain and expand them.



2 Support to allow expansion of NARINE into the international probiotics market is encouraged by the Panel to speed its development in a rapidly maturing market.

3 Continued support for the development of callus-based pharmaceuticals is encouraged because of their improved assay and large-scale production properties.

SECTION 7

STUDENT EDUCATION AND INVESTMENT IN RESEARCH / BIOTECHNOLOGY

There are more than 100 universities and research institutes in Armenia. The education program presented to the Panel is on par with standards of other countries, while remaining traditional. The solid Armenian education foundation and rigor is important, and should be maintained. The number of researchers in Armenia is reaching ~15,000, which include young, engaged faculty that want to improve the education system. Armenian researchers are widely published in indexed journals and have developed international collaborations. Collaborations between different institutions in Armenia are encouraged.

The symposium presentation by Professor Armen Trchounian (YSU) described a wonderfully integrated educational program to train the "new generation" of Armenian microbiologists in biodiversity, physiology and physicochemical biology. Their microbiology programs integrate with bioenergetics, biophysics, biochemistry and geobiology. The curriculum described in this talk is at par with curriculums at international universities.

In general, the Panel was enthusiastic with the level of modern microbiology expertise displayed by Armenian scientists. The Panel commends Armenian education initiatives that involve students in the research being carried out in their universities, which is vital to developing a competitive pool of up and coming Armenian scientists. The level of student training was very high, as exemplified through poster presentations at the symposium in Yerevan and attentive students asking pertinent questions throughout the entirety of the workshop, which is an indicator of the strength of their science education. Students were able to communicate effectively in the English and had in-depth knowledge of their projects. While biotechnology applications were the goal of some projects at YSU, student training, development of young faculty, and basic science research appeared to be a priority.

To further their efforts to better understand the microbial ecology of hot springs in Armenia and the commercialization of microbes,

Armenian scientists are encouraged to explore additional funding opportunities. Among many existing opportunities, potential funding options for building collaborations with US researchers and US student fellowship opportunities can be found at:

Partnerships for Enhanced Engagement in Research (PEER) program
www.nsf.gov/funding/pgm_summ.jsp?pims_id=504726

Partnerships for International Research and Education (PIRE) program at
www.nsf.gov/funding/pgm_summ.jsp?pims_id=505038

International Research Experiences for Students (IRES) program
www.nsf.gov/funding/pgm_summ.jsp?pims_id=12831

Newton's List at the CRDF website
newtonslist.crdfglobal.org

Fulbright Foreign Student Program
foreign.fulbrightonline.org

A blog about student fellowships
www.usnews.com/education/blogs/international-student-counsel/2013/10/29/find-fellowships-for-international-graduate-students

The International Geobiology Course
www.dornsife.usc.edu/wrigley/geobiology

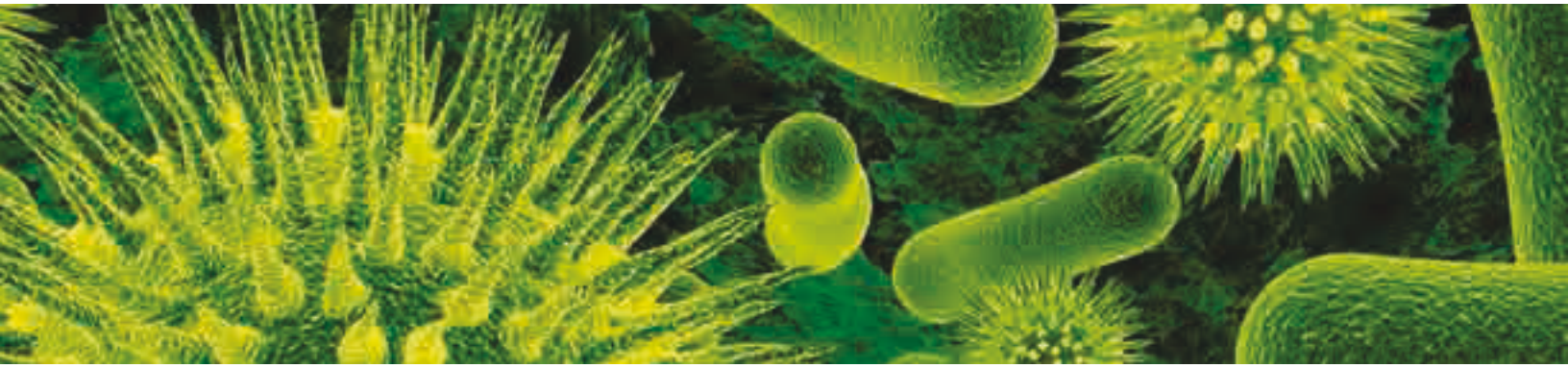
The Microbiology Diversity Course at the Marine Biological Laboratory in Woods Hole, MA
www.mbl.edu/microbialdiversity

The influence of having the opportunity to study abroad was easily observed in some of the faculty as exhibited by their international collaborations and advanced scientific methods. The Panel commends this and recommends continued support of Armenian scientists' international training including taking sabbaticals abroad. The Panel thought that Armenia would be an excellent place for international scientists to visit for short-term collaborations or teaching. Such visits could provide training to so many more Armenian scientists and students than just sending a few students abroad.

The Panel was impressed with potential products and applied research at Armbiotech and YSU, but did not meet with representative of national government agencies aimed at facilitating commercialization. If such an organization does not exist, the Panel recommends establishing an international technology agency to facilitate commercialization of Armenian research products locally and abroad. Besides acting as an agent for applied research, such organizations can assist individual researchers and institutions by providing Material Transfer Agreement (MTA) templates, Confidentiality Agreement templates, strain collection database templates, collaboration agreements, etc., which would protect the intellectual property rights of Armenian scientists.

RECOMMENDATIONS

1 Young researcher and student participation in established international training programs in microbial diversity, geobiology, DNA sequencing and bioinformatics would insure the future of Armenian microbiology and build on their strong foundation of microbiology research.



2 Supporting the education of students in the interdisciplinary fields comprising modern microbiology will be extremely productive and beneficial for the people of Armenia.

3 Armenian microbiologists can continue to leverage their resources and gain technical assistance by partnering with academicians from around the world who are interested in better understanding biodiversity and the natural environment of Armenia.

SECTION 8

CULTURAL COMPONENT OF THE VISIT

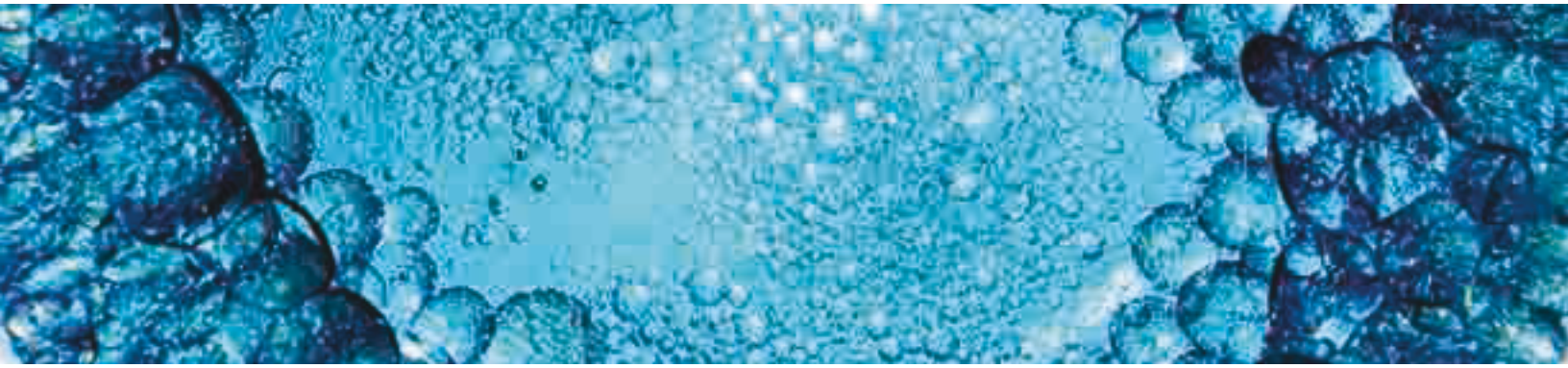
Between the science, the beauty of the countryside, and the beauty of the people of Armenia, the US Panel was very pleased with their experience in this country. Entering Armenia from Georgia, the Panel was driven through incredible mountain scenery, sweeping plains, and small country towns, which definitely produced the feeling of being somewhere very foreign from our own home, but was beautiful to experience. Stopping at a local bakery on the way to Yerevan offered a quick welcome to the delicious Armenian food that the Panel would enjoy for the remainder of the trip, as well as providing their first peak at Armenian culture with traditional breads baked in view of crowds of locals and tourists. While in Yerevan, the Panel was able to enjoy a wealth of food, cultural experiences, and visits with local scientists and students.

On their first night in Armenia, the Panel enjoyed traditional Armenian foods, dance and folksongs at Tavern Yerevan. October 9th was a day packed with a visit to YSU, a site visit to a natural spring in Hanqavan and then Lake Sevan, followed by cultural visits to Garni and Geghard Monastery. The walk up the stairs to the Sevanevank Churches was well worth the effort, with beautiful churches, beautiful khachkar Armenian cross-stones and views of fog rolling down the Areguniats Mountains to the shores of Lake Sevan. Lunch included a special treat, ishkhan (prince trout) from Lake Sevan.

Garni has been occupied since Neolithic times. The Panel walked through the Garni Temple with breathtaking views of the Avan Gorge, a Roman bathhouse with a mosaic depicting the goddess of the ocean and carved vishap stones. The Panel arrived late in the day at Geghar Monastery (originally housing a relic from Christ's crucifixion), marveling at caves used as monastic cells, exploring the 13th century churches in twilight and enjoying the acoustics of a cave church carved out of mountain stone. On October 10th, the Panel visited the ARARAT Brandy factory and signed the Peace Wall. Although the Panel members were aware of the Armenian Genocide, most were unprepared for the scope of this tragedy as respectfully detailed at the Armenian Genocide Memorial. The sad tone of the day was replaced with calm inspiration by a visit to the Echmiadzin Cathedral, the center of Armenian Christianity. Next the group visited the Zvartnots Cathedral (built over 1300 years ago) bathed in the magic lighting of the approaching sunset, which accentuated the beautiful golden and orange colored stones. The day ended with a visit to the Yerevan folk market for some last minute shopping. The Panel members also enjoyed walking through Republic Square at night in Yerevan, observing all the street sculptures near the ANI hotel and visiting outdoor cafes. In a fitting end to the Panel's visit to Armenia, several Panel members were treated to an unobstructed view of Mount Aragats at sunrise from the airport departure lounge. The Panel will always remember the Armenians themselves - as gracious, humble and warm people.

OVERALL PANEL RECOMMENDATIONS FOR ARMENIA

The modern microbiologist requires knowledge of many different specialties, and it would therefore be beneficial to foster further training at all levels through local and international courses, visiting scientist exchanges to and from Armenia or between Armenian institutions/departments, and educational curricula that emphasize interdepartmental training in modern microbiology and microbial diversity methods.



2 In times of limited resources it is necessary to focus on areas that represent unique Armenian niches and build on existing strengths.

3 A governmental repository of template documents to serve as starting points for commercial and academic exchange agreements would be a cost effective way of protecting Armenian resources and encouraging corporations, funding agencies, strain collections and academic researchers to invest in Armenian science. These documents facilitate interaction by clearly defining each party's role and responsibility, and they are considered a necessary first step by most international organizations.

4 Explore more actively foreign sources for funding.

5 The government should consider expanding seed funds to incubate, advance and promote ongoing biotechnology programs.

6 Consider partnering with human microbiome researchers to study the probiotics in NARINE.

7 The Panel was very impressed with the level of research in Armenia and education, and recommends further government support.

CONCLUSIONS AND RECOMMENDATIONS

While it is not a common practice, the Panel recommends that NSF continues to organize this type of workshop as an effective means of gathering information for collaborative international arrangements. It allows a more accurate and informed analysis of the readiness of the research programs and emerging research areas to benefit from NSF support. As we say in America, 'seeing is believing.'

It may further provide the subject country with independent feedback regarding the state of its research program and is especially relevant for countries of the former Soviet Union, which may not have previously had much interaction with US or other international basic or applied research programs. The workshop reported here had an exploratory nature. Materials presented in Georgia and Armenia provided important information regarding attitudes and processes in each country. The invited US participants had highly varied backgrounds and expertise from academic institutions, non-profit and private research, and industry. A diverse group of experts was essential for a multifaceted evaluation of natural and scientific resources available in the visited countries. The highly varied background of the Panel members was synergistic, with each specialist having insight into different aspects of the information provided by the Georgian and Armenian participants and hosts. For example, what is an acceptable and common practice for an academic scientist may be unusual or even unacceptable for an industrial project and vice versa. A computer/bioinformatics specialist, a geo-biologist or a classical microbiologist would most likely have a different perspective regarding what is essential or even standard practice.

A period of extended personal interaction lasting a few days allowed the Panel to cut through language, cultural and perspective differences to ascertain a more accurate picture of what is actually meant by the local participants and hosts. At any scientific meeting, informal interactions are often more valuable and productive than the formal presentations. Extended interactions allow the Panel members to begin to read between the lines. The informal and cultural aspects of the workshop help build trust and understanding amongst the participants from different countries and different organizational positions leading to more effective evaluations.

The following might be considered for future workshops:

The Panel met with a limited number of research groups in leading academic and/or biotechnological institutions selected by the local hosts. The Panel members had opportunities to talk as a group and individually to these scientists. The Panel expressed a desire to meet with scientists from more institutes to enable the Panel to make a more comprehensive analysis of the state of research in each country, rather than in a single institute.

This kind of workshop would benefit from engagement of young, energetic students and junior research faculty. The Panel recommends that the engagement of junior scientists and students be encouraged in future Panels.

Seeing how each country organized their part of the workshop has value in learning about local initiative and what they think is important. Georgian and Armenian organizers presented their most important directions in biological, medical, and biotechnological research. However, the Panel thought that there were areas not covered by the local presenters that were important for overall analysis. Therefore, the Panel recommends that the local countries provide an initial program in advance of the meeting with speaker/institute background information to better allow feedback from the US organizers.

This workshop where invited specialists reviewed and evaluated the state of research and provided recommendations for next steps, specific targets and programs was organized upon request and invitation to the NSF from Georgia's Innovation and Technology Agency to boost collaboration between US and Georgian and Armenian scientists. Such multifunctional workshops are compelling because they provide meaningful, objective, and analytic information to NSF (and potentially other US government agencies), which is difficult or impossible to obtain by other means. The Panel recommends that NSF be receptive to perform (or facilitate) review and evaluation if requested by foreign institutions or other US government agencies regarding basic science, applied research, biotechnology, or even business and innovation, as well as student or educational perspectives. The evaluations and recommendations provided could be used (i) to estimate the significance, quality and feasibility of research, (ii) to see how local programs compare to similar US programs and (iii) to determine how the US can benefit from potential cooperative relationships. The Panel also recommends that NSF may want to be proactive and initiate similar evaluation efforts on their own, especially in regions of potentially high interest to US science, education or innovation.

To be most effective, the workshop reported here should be the first in a series of workshops. An expert Panel of scientists can evaluate research programs, ecological environments, educational programs, applied programs and the potential for individuals or programs to make significant contributions. However, they cannot evaluate specific projects at the level of detail provided in short presentations or discussions. Follow-up workshops similar to normal NSF grant review Panels would be needed to evaluate individual academic or industrial projects. Marketing, industry and business experts are better qualified to evaluate potential products, new technology and commercial feasibility of applied research. The Panel recommends that scientific expert Panels be followed by strategic planning workshops with industry and business experts to evaluate market potential, commercial development stage and comparison to current gold standards.

The Panel was very impressed with the level of science being conducted in Armenia. The Armenian part of the workshop presented vibrant and enthusiastic researchers, students and educators that were engaged in activities close to par with their US counterparts. Education was emphasized and curricula were similar to ones in US universities. Basic research in Armenia included modern microbiology methods limited only by the availability of funding. Some modern equipment was obtained mainly by international collaborations. Armenian scientists trained and collaborated with international groups, which helped to achieve this forward thinking and acting approach. The Panel thought that the Armenian researchers met all three workshop aims (an international quality collection of microorganisms, accessible thermal springs with potential and advantage for microbial diversity research, and suitable programs for basic and applied collaborations). There were several on-going local and international commercial collaborations, and numerous applied projects with significant potential. The Panel universally felt that interactions between US and Armenian scientists would benefit from NSF support, and were at a level that could effectively utilize and leverage this support. Several Panel members thought that establishing an Armenian core facility for PCR and DNA sequencing was appropriate and beneficial, given the amount of research already being performed in Armenia using these techniques, much of which is currently farmed out to external providers.

The Panel was also impressed with the enthusiasm of the GITA representatives and their desire to create a system for innovation and technology development in Georgia. Irakli Kashibadze presented GITA's support for innovation and technology in all fields of economy, high-tech products, and internet infrastructure. However, the Panel members were left with questions regarding what part of this support goes to basic science and particularly to the biotechnology, biology and life science. All Georgian scientists the Panel met were senior researchers. Few modern microbiology techniques were being practiced, such as sequence-based strain identification, collection of environmental metadata or microbial community analyses. Georgian biological science needs an influx of molecular techniques and next generation –omics approaches, beyond GITA's support for the organization of the first Biotechnology Center in Georgia. A collection catalog with standard strain information is necessary to leverage the value of strain collections. The application of sequencing techniques are critically important to improve the large Georgian culture collections that are well below international standards with many organisms only classified by the assignment of taxonomic names in agreement with classic published rules. The Panel had the impression that Georgian researchers focused on obtaining a large number of isolates that might someday have commercial interest, but until then, rigorous characterization was unnecessary. This is a standard commercial approach. If the culture collections are to have merit in basic

science programs, the Panel recommends that resources would be better spent improving characterization of current strains rather than obtaining new strains that lack essential characterizations. However, once these measures are put in place, continued strain isolation or metagenome analyses would provide better resources with more extensive metadata.

The absence of students and energetic young faculty gave the impression that biology and microbiology are not very popular in Georgia these days, and that a limited number of young people go into science because of insufficient funding and low wages. GITA could play a major role in advertising and promoting the biological, environmental and life sciences. It would elevate and provide prestige for biological sciences in their scientific society if some financing from the Mini-Grant Program established by GITA would go to young faculty or support graduate students and/or postdoctoral researchers. The broad engagement of students and young faculty should be emphasized in Panel and NSF recommendations because it will be beneficial for modernization and growth and development of scientific directions. The Panel thought that Georgian scientists could benefit from international collaborations and visiting international labs to learn new techniques and get a better sense of current research practices. On the whole, the Georgian scientists showed the Panel some interesting projects worthy of international collaborations.

Scientists in both countries provided a litany of common biotech projects, most of which are being universally targeted around the world. While a few successful experiments can lead to a paper or grant, product development requires more in depth characterization of broader on- and off-pathway effects, reagent specificities and multiple assay conditions. Most applied research and product development was presented at a basic science level and not with the rigors required for commercial development, leaving the Panel to wonder if this type of data is available. Product development would benefit from government seed money to carry out these more applied requirements, which would better position Georgian and Armenian scientists for commercialization of research activities.

The Panel encourages higher levels of funding by Georgian agencies to energize Georgian microbiology, bring it further into the modern era and encourage bright young people to view research as a valuable career. The Panel also encourages further funding by Armenian agencies to continue to advance research, stimulate young people to become scientists, foster growth of current researchers and maintain the current high level of research. While Armenia has a platform and strong basis for further development of applied research, it needs financial support. The Panel thinks that collaborations between the US and Georgian and/or Armenian scientists in biotechnological, bioremediation, and applied research would be beneficial for US scientists by providing access to research and little studied natural recourses. Hence NSF should seriously consider facilitating and supporting such interactions. The Panel thought that US, Georgian and Armenian scientists could develop challenging, interdisciplinary research projects and collaborative projects involving novel microbial strains, environmental metagenomic diversity and integration of functional and next generation –omics approaches.

APPENDIX 1 | GEORGIA: WORKSHOP PROGRAM DETAILS

CONTEXT

Microorganisms that thrive at relatively (41°-80°C) or extremely (80°-122°C) hot environments are called thermophiles or hyperthermophiles, respectively. Thermophilic organisms were discovered among bacteria, archaea, and mycelial fungi. Many (hyper) thermophiles tolerate other environmental extremes such as high acidity, high pressure or radiation levels, which makes them valuable subjects for applied microbiology and biotechnology. The Caucasus Mountains located between the Black and the Caspian seas is rich in deposits of various minerals, oil and gas, as well as mineral waters and thermal springs. This region is poised for major discoveries, since the thermal features here have not undergone intensive study with advanced methods.

Georgia, occupying 80% of the Southern slopes of comparatively young mountain ridge-Caucasus is extremely diverse biologically and geologically. That allows identifying great variety of organisms including so called extremophilic microorganisms growing under extreme of conditions. The existence of hat water sources (above 1000 hot springs), alkali soils, acidic reservoirs, great number of high salt content soils is a very good area for the isolation of thermophiles, alkaliphiles, acidophiles, halophiles, etc. The Collections of microorganisms of different taxonomic groups (Agricultural University of Georgia,) accounting almost 8.000 strains contain up to 800 strains-extremophiles and is a good base for the creation of qualitatively new technologies.

OCTOBER 3, 2015

Experts Group Arrival at
Vere Palace Hotel (22-24 G. Kuchishvili str.)

OCTOBER 4, 2015

18:00 – 21:00

Sight Visit and Welcome Dinner in Mtskheta
(old capital of Georgia)
Departure from hotel (17:30)

OCTOBER 5, 2015

09:30 - 11:00

Agricultural University of Georgia (AUG)
Durmishidze Institute of Biochemistry and Biotechnology
Departure from the hotel (09:00)

11:30 – 13:00

Lunch at Vere Palace Hotel

13:00 – 13:30

Registration

13:30 – 13:45

Opening Remarks:

DIMITRY KUMSISHVILI
Minister of Economy and Sustainable Development

IRAKLI KASHIBADZE
Georgia's Innovation and Technology Agency

MARINE CHITASHVILI
Rustaveli National Science Foundation – TBC

PANEL 1

GIORGI KVESITADZE (Chair)
The Georgian National Academy of Sciences, Georgia

TATIANA VISHNIVETSKAYA (Co-Chair)
University of Tennessee Knoxville, USA

13:45 – 14:10

GIORGI KVESITADZE
President of the Georgian National Academy of Sciences

LALI KUTATELADZE
Professor AUG: Extremophiles from differing ecological niches of Georgia

14:10 – 14:30

TATIANA VISHNIVETSKAYA
Staff Scientist University of Tennessee: Biodiversity of plant-biomassdegrading bacteria in the springs of Yellowstone National Park

14:30 – 14:50

ROBERT RAMALEY
Emeritus Professor University of Nebraska: Isolating "new" slowly growing thermophilic bacteria and is it really true that everything is everywhere?

14:50 – 15:10

VLADIMER ELISASHVILI

Professor AUG: Wood-rotting basidiomycetes biosynthetic and degradation potential evaluation and application (includes translation)

15:10 – 15:30

TINATIN SADUNISHVILI

Professor AUG, Georgian National Academy of Sciences: Bacteriophages against plant pathogenic bacteria

15:30 – 16:00

NINO GAGELIDZE

Professor AUG, Collection of bacterial strains (includes translation)

16:00 – 16:30

Coffee Break

PANEL 2

TINATIN SADUNISHVILI (Chair)

Agricultural University of Georgia, Georgia

JOHN SPEAR (Co-Chair)

Colorado School of Mines, USA

16:30 – 17:00

LIA AMIRANASHVILI

Professor AUG: Bacterial metabolites (includes translation)

17:00 – 17:20

LORI ZIOLKOWSKI

Assistant Professor University of South Carolina: Assessing carbon sources to thermophilic microorganisms

17:20 – 17:40

FRAN PERLER

Principal Investigator New England BioLabs: Protein Splicing: Inteins in Action

17:40 – 17:80

JOHN SPEAR

Professor Colorado School of Mines: The Microbiome of a Hot Spring Transect

18:00 – 18:20

JORDAN BIRD

Student University of Tennessee: Single Cell Genomics Provides Insights into Microbial Communities Dominated by Deeply-Branching Organisms

18:20 – 18:40

WESLEY SWINGLEY

Professor Northern Illinois University: Leveraging diverse sequencing approaches for assembling microbial dark matter

18:40 – 19:00

ERIC BECRAFT

Post Doctoral Bigelow Laboratory for Ocean Sciences: Untangling the Deep Genealogy of Microbial Dark Matter in Extreme Environments

19:00 – 19:30

EKATERINE LEPSVERIDZE

Professor Ilia State University: Research Commercialization Opportunities in Georgia in the direction of Biology and Biotechnology

20:30 – 23:00

Dinner

OCTOBER 6, 2015

10:00 – 18:00

Kakheti Sight Visit – Shiraki

Departure from the Hotel (09:30)

Arrival in Shiraki Valley and visit local high temperature sites (13:00)

University Campus, Potential Regional Thermophile Lab (15:00)

Dinner (16:00)

OCTOBER 7, 2015

10:00 – 12:00

Round Table and Final Wrap Up

12:00 – 13:00

Lunch

13:30

Departure to Armenia

APPENDIX 2 | ARMENIA: WORKSHOP PROGRAM DETAILS

CONTEXT

Microorganisms that thrive at relatively (41°-80°C) or extremely (80°-122°C) hot environments are called thermophiles or hyperthermophiles, respectively. Thermophilic organisms were discovered among bacteria, archaea, and mycelial fungi. Many (hyper) thermophiles tolerate other environmental extremes such as high acidity, high pressure or radiation levels, which makes them valuable subjects for applied microbiology and biotechnology. The Caucasus Mountains located between the Black and the Caspian seas is rich in deposits of various minerals, oil and gas, as well as mineral waters and thermal springs. This region is poised for major discoveries, since the thermal features here have not undergone intensive study with advanced methods. Numerous geothermal springs with temperatures in the range from 27 and 70 oC and with neutral pH are found in Armenia. Thermophilic microbial communities of these springs can represent a rich source of novel organisms and processes. The existence of geothermal springs, alkaline-saline soils, subterranean salt deposit, metal mines is a very good area for the isolation of thermophiles, alkaliphiles, halophiles, metalophiles. The Collections of exthremophiles belonging to the different taxonomic groups is a good base for the creation of qualitatively new technologies and could improve the dialogue between science and industry.

OCTOBER 7, 2015

Experts Group Arrival at
Ani Plaza Hotel (Sayat-Nova str. 19, 0001, Yerevan)

OCTOBER 8, 2015

09:30 - 11:45

Scientific and Production center "Armbiotechnology"
SNPO NAS RA
Microbial Depositary Center – E.G. Afrikian,
Academician of NAS RA
Departure from the hotel (09:15)

11:30 – 13:00

Lunch at Ani Plaza Hotel

13:00 – 13:45

Registration

13:45 – 14:00

Opening Remarks:

SAMVEL HAROUTIUNIAN
Chairman of the State Committee of Science (SCS) of the Ministry of Education and Science of the Republic of Armenia

ASHOT S. SAGHYAN
Academician of NAS RA, Professor, Doctor in Chemistry, Scientific and Production center "Armbiotechnology" SNPO NAS RA

ARMEN TRCHOUNIAN
Corresponding member of NAS RA, Professor, Doctor in Biology, Head of the Department of Microbiology, Microbe and Plant Biotechnology, Yerevan State University

PANEL 1

ARMEN TRCHOUNIAN (Chair)
Yerevan State University

TATIANA VISHNIVETSKAYA (Co-Chair)
University of Tennessee Knoxville, USA

14:00 – 14:20

ARMEN TRCHOUNIAN
Microbiology: Education and Research in Armenia

14:20 – 14:40

TATIANA VISHNIVETSKAYA
Staff Scientist University of Tennessee: Biodiversity of plantbiomass-degrading bacteria in the springs of Yellowstone National Park

14:40 – 15:00

ROBERT RAMALEY
Emeritus Professor University of Nebraska: Isolating "new" slowly growing thermophilic bacteria and is it really true that everything is everywhere?

15:20 – 15:40

NELI HOVHANNISYAN
Scientific and Production center "Armbiotechnology" SNPO NAS RA, Scientific and biotechnological potential of the "Armbiotechnology" center

15:40 – 16:00

FRAN PERLER

Principal Investigator New England BioLabs: Protein Splicing: Inteins in Action

16:00 – 16:30

Poster Presentations with Coffee Break

PANEL 2

HOVIK PANOSYAN (Chair)

Yerevan State University

JOHN SPEAR (Co-Chair)

Colorado School of Mines, USA

16:30 – 16:50

HOVIK PANOSYAN

YSU, Thermophiles harbored in Armenian Geothermal springs

16:50 – 17:10

JOHN SPEAR

Professor Colorado School of Mines: The Microbiome of a Hot Spring Transect

17:10 – 17:30

LORI ZIOLKOWSKI

Assistant Professor University of South Carolina: Assessing carbon sources to thermophilic microorganisms

17:30 – 17:50

JORDAN BIRD

Student University of Tennessee: Single Cell Genomics Provides Insights into Microbial Communities Dominated by Deeply-Branching Organisms

17:50 – 18:10

WESLEY SWINGLEY

Professor Northern Illinois University: Leveraging diverse sequencing approaches for assembling microbial dark matter

18:10 – 18:30

ERIC BECRAFT

Post Doctoral Bigelow Laboratory for Ocean Sciences: Untangling the Deep Genealogy of Microbial Dark Matter in Extreme Environments

18.30-19.00

Poster presentations with Coffee Break

19:30 – 23:00

Dinner

OCTOBER 9 , 2015

09:30 – 11:00

Visit to Yerevan State University, Department of Microbiology and microbe and Plant biotechnology

11:00 – 18:00

Visit to Hanqavan geothermal spring, Lake Sevan
Departure from the YSUI (11:00)
Arrival in Hanqavan (12:00)
Arrival Lake Sevan (14:00)
Dinner in Sevan (16:00)

OCTOBER 10 2015

09:30 – 11:30

Round Table and Final Wrap Up

11:30 – 13:00

Visit to Matenadaran

13:00 – 14.30

Lunch

14.30-16.00

Echmiadzin Cathedral

16.00-17.00

ARARAT brandy company

19.00-23.00

Workshop working Dinner and report draft writing

APPENDIX 3 | BIOGRAPHIES OF US PARTICIPANTS

DR. TATIANA A. VISHNIVETSKAYA
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Dr. Vishnivetskaya is a Research Associate III in the Center for Environmental Biotechnology (CEB) at the University of Tennessee (UT). Dr. Vishnivetskaya holds a Ph.D. (2003) in Biochemistry from Russian Academy of Sciences and a M.Sc. (1990) in Biology with major in Microbiology from the Lomonosov Moscow State University, Russia. She has been presented Significant Event Awards from Department of Energy, and scholarship from NASA Astrobiology Institute. Her interests lay in uncovering microbial community structure and biodiversity of various extreme environments including hot springs, soils and sediments from polluted sites, deep subsurface permafrost, tundra soils, and animal/human microbiome. In her research Dr. Vishnivetskaya is applying a variety of classical microbiological and high-throughput techniques, such as quantitative real time PCR, microarrays, hybridization, next generation sequencing, single cell genomics, metagenomics, metaproteomics, metatranscriptomics. Her experience is reflected on numerous peer-reviewed publications including Nature and ISME.

DR. ROBERT RAMALEY

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Dr. Ramaley is Emeritus Professor in the Department of Biochemistry and Molecular Biology at the University of Nebraska Medical Center, Omaha, Nebraska. Dr. Ramaley holds a Ph.D. (1964) in Microbiology and Physiological Chemistry from University of Minnesota; a M.Sc. (1962) in Agricultural Biochemistry from Ohio State University; and a B.Sc. (1959) in Bacteriology from Ohio State University. His primary research lays in biochemistry and biology of thermophilic microorganisms, thermostable enzymes; and environmental health. His studies center on the cloning and expression of developmentally regulated genes involved in bacterial sporulation, the enzymes involved in microbial pathogenicity and the enzymes and proteins from extremely thermophilic bacteria.

DR. JOHN SPEAR

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Dr. Spear is Professor in the Department of Civil and Environmental Engineering at the Colorado School of Mines, Golden, Colorado. Dr. Spear holds a Ph.D. (1999) and a M.Sc. (1994) in Environmental Science and Engineering from Colorado School of Mines; and a B.A. (1984) in Biology from University of California, San Diego. He is a co-director of the International GeoBiology Summer course on Catalina Island, which involves lectures, labs, field trips and independent research for advanced graduate and postdoctoral students. Dr. Spear has been presented numerous awards including Martin Luther King, Jr. Diversity Recognition Award, and Outstanding Teacher of the Year from the Department of Civil and Environmental Engineering. He is interested in microbial diversity present in diverse environments such as the Canadian High Arctic or hotsprings from both cultural, metabolic and a DNA sequence perspectives.

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Dr. Swingley is Assistant Professor, Department of Biological Sciences, Northern Illinois University, Dekalb, Illinois. Dr. Swingley holds a Ph.D. (2006) in Microbiology from Arizona State University and a B.Sc. (2001) in Biochemistry from Case Western Reserve University, Cleveland, Ohio. His research interests focus on microbial ecology of extreme environments, comparative genomics, metagenomics, evolution and the origin of life. Each year Dr. Swingley presents talks focused on science education for the public and the next generation scientists. He hosted NSF REU-site students during summers of 2013-2014. Each summer two to three students participated in this exciting program that covered two field sites, the Nachusa Tallgrass Prairie Restoration and the Calumet Wetlands steel waste site. His research has been published in numerous peer-reviewed journals, including Nature Communication and PNAS.

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Dr. Ziolkowski is Assistant Professor in the Department of Earth and Ocean Sciences at the University of South Carolina (USC). Dr. Ziolkowski holds a Ph.D. (2009) in Earth System Science from the University of California, Irvine; a M.Sc. (2000) in Chemical Oceanography from Dalhousie University, Canada; and a B.Sc. (1998) in Environmental Chemistry from University of Waterloo, Canada. Her research interests center on the fate of natural and anthropogenic organic matter during climate change especially in regions with continuous permafrost. Dr. Ziolkowski co-chaired a number of sessions at the Goldschmidt, AGU and Ocean Sciences meetings. She was competitively selected to be a participant at the Next Generation Polar Researcher Leadership Symposium, which held on Catalina Island in May 2-9, 2015.

DR. FRAN PERLER
Retired

Previously from New England BioLabs
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Dr. Perler, retired, served for 35 years as Principal Investigator in the New England BioLabs. Dr. Perler holds a Ph.D. (1977) in Genetics from the University of North Carolina, Chapel Hill; a B.Sc. (1972) in Biology from Brooklyn College, City University of New York. She was a Visiting Lecturer at Harvard School of Public Health, worked as a Visiting Scientist in the Academia Sinica, Taipei, Taiwan, and the Chinese Academy of Medical Sciences, Beijing, China, and participated in the program for Improving Graduate School Education at the Kyushu University, Fukuoka, Japan. Dr. Perler's interests combined commercial and basic scientific goals. She studied potential diagnostic and vaccine candidates for Malaria and River Blindness; DNA polymerases and replication enzymes from Archaea; identified inteins in Archaea; defined the protein splicing mechanisms; and studied mosquito proteomics. Dr. Perler designed and curated for twenty years (1994-2015) InBase, the on-line intein database and was a member of Editorial Board for Molecular and Cellular Proteomics.

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Mrs. Polosukhina is a Research Specialist in the Department of Surgical Urology at the Vanderbilt-Ingram Cancer Center. Mrs. Polosukhina holds a M.Sc. (1988) in Cytology and Genetics from Novosibirsk State University, Novosibirsk, Russia. She has extensive experience in Biochemistry, Cell Biology and Molecular Biology. Her research examines the roles of transforming growth factor (TGF) -beta signaling in carcinogenesis.

DR. ERIC BECRAFT

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Dr. Becraft is a Postdoctoral Scholar in the Bigelow Laboratory for Ocean Sciences. Dr. Becraft holds a Ph.D. (2013) in Ecology and Environmental Sciences from the Montana State University; and a B.Sc. (2005) in Microbiology from the University of Texas at Austin. Dr. Becraft is interested in the identification of uncultured Bacterial and Archaeal (i.e. microbial dark matter) and their contributions to the evolutionary history of microbial life on Earth. He studies microbial diversity, ecology, and evolution in the context of microbial community structure and function. His interests range from microbiology in extreme environments and microbial speciation to the role microorganisms play in global geochemical cycling.

JORDAN BIRD

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Jordan Bird is a Ph.D. student and the SCALE-IT Fellow in the Microbiology Department at the University of Tennessee (UT) Knoxville. Jordan obtained his B.Sc. degree in Biology in December 2011 from University of Central Arkansas (UCA). Currently he is pursing his Ph.D. in Microbiology from the UT. Jordan has received training through the NSF REU Fellowship in Microbiology at Virginia Tech and the SCALE-iT NSF Traineeship in Computer Science at UT. In his work, Jordan is combining his training in microbiology and bioinformatics with the geobiochemical techniques to examine biological element cycling within anaerobic, marine sediments. Jordan uses single-cell sequencing technology to examine the genomes of these uncultured archaea and bacteria for clues to their role in these low energy communities. His passion is to discover how Earth and its microbes evolve.

DRAKE MCCRIMMON

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Drake McCrimmon is a M.Sc. student in Geology at the University of South Carolina. He holds a B.Sc. (2015) in Chemistry from the Louisiana State University. His previous work includes investigating the formation of Environmentally Persistent Free Radicals on contaminated Superfund soils, looking at n-alkane biomarkers in arctic soils, and investigating Polycyclic Aromatic Hydrocarbon (PAH) distribution and degradation in Louisiana wetlands as a result of Hurricane Isaac in 2012. Drake's interests lie in global change and biogeochemistry and his current work is in studying carbon inputs for microbes living in cryoconite holes on the surface of glaciers.

Principal Investigator of the project:

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