

Remote Sensing Aqueous Surface
Processes on Planets Red and Blue:
From Chemical Weathering Mineralogy
on Mars to Water Temperature in
Alaska's Riverine Corridors

Thesis by
Samantha Rose Baker

In Partial Fulfillment of the Requirements for
the degree of
Doctor of Philosophy



CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

2026
(Defended May 21, 2026)

© 2026

Samantha Rose Baker
ORCID: 0009-0001-7705-3261

ACKNOWLEDGEMENTS

Thank you to my research advisors, Bethany Ehlmann and Michael Lamb. I would like to thank Bethany for her invaluable guidance over the course of my Ph.D. and for the substantial time and thought that she dedicates to all her students. With her guidance, I feel much better prepared to be a scientist in this field. I would like to thank Mike for being excited to support me in my river research even though it deviates a bit from the typical work of the group, and for fostering a distinctly interdisciplinary and collaborative lab environment.

Thank you to my thesis committee members, Katherine de Kleer, Woody Fischer, and Christian Frankenberg for their support, advice, and feedback throughout my Ph.D. and thesis-writing process.

Thank you to all the members of the Ehlmann and Lamb lab groups for your tremendous support, collaboration, and camaraderie over my time here at Caltech. It has been a great joy to get to work every day with such wonderful people and great friends. I have loved hearing about your work, and thank you for the many conversations in group meeting, group lunches, or around the office about science, grad school, career advice, life, and more. I have learned so much from you, and I admire how you all ask excellent questions and give excellent answers.

Thank you to the Alaska team and community partners for your support in developing my research, for field data collection, and for helping me to place my work in the context of the dynamic evolution of the Arctic environment. I have really appreciated the opportunity to collaborate with all of you

Thank you to all the friends that I have made over my time here: in my lab groups, in GPS, at Caltech, and beyond. You all have made this experience as special as it was, and I am so glad to have found community with all of you. I admire your kindness, your curiosity, your joy, and your adventurousness. Thanks especially to Yu Yu Phua for being a

wonderful roommate and friend and to Abby Keebler for being a wonderful officemate and friend.

Finally, an infinite amount of thanks to my wonderful family. Thank you to my parents for first telling me that rocks tell stories when I was seven and supporting me at every turn since I decided that I want to try to understand those stories for the rest of my life. Your unconditional love and support have meant the world to me. Thank you to my sister Anna, who is the reason why I love space and has been beside me for every step of this journey. I want to talk about rocks with you forever, and you are my best friend in the whole world. You are the best family I could ever have asked for, and I love you all so much.

ABSTRACT

Ever since satellites were first launched into space in the 1950s, they have been utilized for critical science on Earth and eventually, around other planets as well. In Chapters 2 and 3, we use hyperspectral imagery and other remotely sensed data to examine the formation of aluminum phyllosilicate on Mars. Al-phyllosilicates across Mars have been proposed to have formed from extensive water leaching of basalt, though regional-specific studies suggest diversity between Al-phyllosilicate-bearing regions. Considering this complexity, in Chapter 2, we reexamine Al-phyllosilicate and its associated minerals in the Nili Fossae region. Using hyperspectral imagery from the CRISM instrument, we used Gaussian fitting to automatically identify and map Al-phyllosilicate and its associated minerals. We find that in contrast to prior interpretations, the Al-phyllosilicate in Nili Fossae most likely formed from weathering of an aluminous volcanic ash rather than from extensive leaching of basalt. In Chapter 3, we expand this analysis to a global survey of 6 Al-phyllosilicate-bearing regions on Mars. We examine the composition and stratigraphy of each region to determine their weathering histories, and we compare the regions to place them in a global context. We find that most of the Al-phyllosilicate on Mars is more consistent with volcanic ash alteration rather than extensive basalt leaching, though some regions are more consistent with basalt leaching. We conclude that the Al-phyllosilicate on Mars did not all form from one process, and our results demonstrate the potential for less extensive alteration and more widespread ash-producing volcanism in Mars' history than previously thought. In addition to composition, remotely sensed data can also be used to measure temperature. In Chapter 4, we use surface temperature derived from Landsat satellite data to examine the spatial and seasonal patterns of river temperature in Arctic rivers and their surrounding floodplains. Water temperature in the Arctic is interwoven with numerous environmental processes and is responding rapidly to the changing climate, but it is poorly monitored. We demonstrate that the Landsat temperature dataset is accurate for application to Arctic river environments, and we generate and examine water temperature maps of the Yukon River watershed. With these, we show that satellite-based temperature measurements can and should be used to address critical environmental questions in this region.

PUBLISHED CONTENT AND CONTRIBUTIONS

Baker, S.R. and Ehlmann, B.L. (in review). “Aluminum phyllosilicate and jarosite formation through alteration of reworked Al/Si-rich volcanoclastic sediments in Nili Fossae, Mars”. In: *Journal of Geophysical Research: Planets*.

S.R.B participated in the conception of the project, developed methodology to map minerals, analyzed the spectral and stratigraphic data, prepared figures, and participated in the writing of the manuscript.

- *Adapted for the contents of Chapter 2*

Baker, S.R. and Lamb, M.P. (in review). “Remote sensing water temperature in permafrost riverine corridors”. In: *Water Resources Research*.

S.R.B participated in the conception of the project, generated water temperature maps, analyzed the remote sensing and in situ data, prepared figures, and participated in the writing of the manuscript.

- *Adapted for the contents of Chapter 4*

TABLE OF CONTENTS

Acknowledgements.....	iii
Abstract	v
Published Content and Contributions.....	vi
Table of Contents.....	vii
List of Illustrations.....	xi
List of Tables.....	xiv
List of Acronyms.....	xv
 Chapter I: Introduction	 1
1.1 Phyllosilicates on Mars	1
1.2 Summary of Chapters 2 and 3.....	3
1.3 Arctic riverine corridor temperature	5
1.4 Summary of Chapter 4	6
1.5 References	7
 Chapter 2: Aluminum phyllosilicate and jarosite formation through alteration of reworked Al/Si-rich volcanoclastic sediments in Nili Fossae, Mars	 12
2.1 Introduction	14
2.2 Study Area.....	19
2.3 Methods.....	20
2.3.1 Data processing	20
2.3.2 Mineral identification.....	21
2.3.3 Examination of mineralogic and stratigraphic relationships and context	27
2.4 Results	27
2.4.1 Mineral identification.....	27
2.4.2 Regional-scale context of kaolinite	33
2.4.2.1 Topography and kaolinite	35
2.4.2.2 Case study of a kaolinite-bearing erosional topographic low (21.3°N, 72.9°E)	36
2.4.2.3 Case study near Jezero Crater (77.3°E, 18.4°N)	40
2.4.2.4 Thicknesses of the kaolinite deposits	41
2.4.3 Relationship between kaolinite, jarosite, and Fe oxide	42
2.4.3.1 Nili Fossae main trough (74.3°E, 22.5°N; 74.6°E, 22.1°N)	43
2.4.3.2. Northwest of the main Nili Fossae trough (74.9°E, 26.6°N)	49
2.4.3.3 East of Nili Fossae, west of Isidis Planitia (21.9°N, 78.2°E).....	52
2.4.3.4 Erosional topographic low west of the main trough	

(21.3°N, 72.9°E).....	53
2.4.3.5 Disrupted kaolinite and jarosite deposits.....	54
2.5 Discussion	55
2.5.1 Formation of Al Phyllosilicate in Transported Materials.....	55
2.5.2 Jarosite and Fe oxide as products of localized Fe-bearing water	57
2.5.2.1 Jarosite association with phyllosilicates	58
2.5.2.2 Sulfur source for jarosite formation.....	59
2.5.2.3 Iron source for jarosite formation	60
2.5.2.4 Relative timing of phyllosilicate and jarosite formation ..	60
2.5.3 Proposed Geologic History	62
2.5.4 Jezero Crater and the Mars 2020 mission.....	63
2.5.5 Nature of alteration: Nili Fossae compared to Mawrth Vallis and Terra Sirenum.....	64
2.5.6 Implications for regional chemistry and environmental conditions	67
2.6 Conclusions	69
2.7 References	71
Chapter 3: A global survey of aluminum phyllosilicate formation across Mars:	
Origin from aluminous volcanoclastic alteration and basalt leaching	84
3.1 Introduction	85
3.2 Previous studies of Al-phyllosilicate regions	88
3.3 Methods.....	93
3.3.1 Data processing	93
3.3.2 Mineral identification.....	94
3.3.3 Examining stratigraphic relationships and geologic context	97
3.4 Results	98
3.4.1 Global distribution of Al-phyllosilicate and accompanying phases	98
3.4.2 Comparative spectral analysis of Al-phyllosilicate and accompanying phases.....	99
3.4.2.1 Al-phyllosilicate mineralogy	100
3.4.2.2 Al-phyllosilicate + jarosite mixtures	104
3.4.2.3 Fe oxide.....	106
3.4.3 Stratigraphic association of Al-phyllosilicate and accompanying phases	108
3.4.3.1 Al-phyllosilicate formation from weathering sequences	108
3.4.3.1.1 Hellas Planitia	108
3.4.3.1.2 Eridania Basin, western Terra Sirenum.....	113
3.4.3.2 Al-phyllosilicate formation from volcanoclastic alteration.....	116
3.4.3.2.1 Nili Fossae.....	116
3.4.3.2.2 Libya Montes	120
3.4.3.2.3 Terra Sirenum	123

3.4.3.2.4 Valles Marineris	125
3.4.3.2.5 Mawrth Vallis	129
3.5 Discussion	132
3.5.1 Formation of Al-phylosilicate and associated minerals	132
3.5.1.1 Al-phylosilicate formation as part of a pedogenic leaching sequence.....	132
3.5.1.2 Al-phylosilicate and jarosite-alunite formation from silicic volcanoclastic deposits	133
3.5.1.2.1 Formation of Al-phylosilicate and Fe/Mg-phylosilicate from distinct protoliths.....	133
3.5.1.2.2 Formation of jarosite–alunite and Fe oxide from volcanic ash	135
3.5.1.3 Mawrth Vallis, a special multi-process case?.....	137
3.5.2 Implications of Al-phylosilicate formation from ash for Mars’ volcanism	138
3.6 Conclusions	139
3.7 References	142
Chapter 4: Remote sensing water temperature in permafrost riverine corridors	
4.1 Introduction	153
4.2 Study Location and Methods	155
4.2.1 Study locations	158
4.2.2 Landsat derived temperature data.....	160
4.2.3 Creation of water-only masks for temperature-mapping	161
4.2.4 Comparison to other data	164
4.3 Results	166
4.3.1 Ground truthing and error assessment	166
4.3.2 The Koyukuk River.....	169
4.3.2.1 Comparing surface temperature to temperature at depth	175
4.3.3 The Yukon-Tanana River confluence at Tanana town.....	178
4.3.4 The Yukon River at Beaver	182
4.4 Discussion	185
4.4.1 Vertical temperature structure	185
4.4.2 Seasonal patterns in water temperature	186
4.4.3 Spatial patterns in water temperature	187
4.4.4 Applications of remotely sensed water temperature to the Arctic	189
4.5 Conclusions	192
4.6 References	194
Chapter 5: Synthesis, Implications, and Outstanding Questions.....	
5.1 Chapters 2 and 3	203
5.2 Chapter 4	207

5.3 Conclusions	209
5.4 References	210

LIST OF ILLUSTRATIONS

<i>Number</i>	<i>Page</i>
Chapter 2: <i>Aluminum phyllosilicate and jarosite formation through alteration of reworked Al/Si-rich volcanoclastic sediments in Nili Fossae, Mars</i>	
2-1 Al-phyllosilicate-bearing regions with jarosite and/or alunite	15
2-2 Endmember Al-phyllosilicate formation scenarios	16
2-3 Endmember CRISM and laboratory spectra.....	23
2-4 Gaussian width vs. absorption center for spectra	26
2-5 Examples of Gaussian curve fits to spectra	28
2-6 Nili Fossae endmember CRISM and laboratory spectra	30
2-7 Fe oxide in Nili Fossae.....	32
2-8 Distribution of detected alteration products in Nili Fossae	33
2-9 Location of subsequent Al-phyllosilicate figures	35
2-10 Topographic context of Al-phyllosilicate	36
2-11 Mineralogy of an eroded topographic low	38
2-12 Phyllosilicates in Jezero Crater	40
2-13 Kaolinite thicknesses in Nili Fossae	42
2-14 Image example: A053	45
2-15 Image example: 9971	47
2-16 Image example: 64D9	48
2-17 Image example: AB0A	51
2-18 Image example: 3584	53
2-19 Image example: ABCB	54
2-20 Proposed Nili Fossae geologic history	63

Chapter 3: *A global survey of aluminum phyllosilicate formation across Mars: Origin from aluminous volcanoclastic alteration and basalt leaching*

3-1 Al-phyllosilicate regional diversity comparison.....	101
3-2 Regional mineral endmembers	104
3-3 Mixed Al-phyllosilicate and jarosite.....	106
3-4 Global Fe oxide examples.....	107
3-5 Hellas Planitia mineral map	109
3-6 Image example: 13D3A	110
3-7 Image example: 643D	112
3-8 Terra Sirenum mineral map	113
3-9 Image example: 96FE	115
3-10 Nili Fossae mineral map	117
3-11 Image example: A053	118
3-12 Image example: AB0A	119
3-13 Libya Montes mineral map	120
3-14 Image example: B0CB.....	122
3-15 Image example: 132BC.....	124
3-16 Valles Marineris mineral map.....	125
3-17 Image example: AD3D	126
3-18 Image example: B6C5.....	128
3-19 Mawrth Vallis mineral map	130
3-20 Image example: 3BFB	131

Chapter 4: *Remote sensing water temperature in permafrost riverine corridors*

4-1 Study locations in Alaska.....	159
4-2 River temperature cross-section.....	163
4-3 Ground truthing Landsat temperature data	168
4-4 Huslia data	171
4-5 Huslia map details	173
4-6 Sinuous oxbow lake example.....	175

4-7 Water temperature at surface vs. depth: Huslia	177
4-8 Tanana data.....	179
4-9 Tanana map details.....	181
4-10 Beaver data	183
4-11 Beaver map details	185

LIST OF TABLES

<i>Number</i>	<i>Page</i>
<i>Chapter 2: Aluminum phyllosilicate and jarosite formation through alteration of reworked Al/Si-rich volcanoclastic sediments in Nili Fossae, Mars</i>	
2-1 Relevant minerals and their absorptions	22
2-2 Mineral identification process and criteria	25
2-3 Kaolinite thickness in Nili Fossae.....	41
 <i>Chapter 3: A global survey of aluminum phyllosilicate formation across Mars: Origin from aluminous volcanoclastic alteration and basalt leaching</i>	
3-1 Relevant minerals and their absorptions	96
3-2 Mineral identification process and criteria	98
 <i>Chapter 4: Remote sensing water temperature in permafrost riverine corridors</i>	
4-1 Descriptions of Alaska study locations.....	159

LIST OF ACRONYMS

ASTER. Advanced Spaceborne Thermal Emission and Reflectance Radiometer

CRISM. Compact Reconnaissance Imaging Spectrometer for Mars

CTX. Context Camera

DEM. Digital elevation model

EVI. Enhanced vegetation index

HiRISE. High Resolution Imaging Science Experiment.

LST. Land Surface Temperature.

mNDWI. Modified normalized difference water index

MOLA. Mars Orbital Laser Altimeter

MTRDR. Map projected targeted reduced data record

NDVI. Normalized difference vegetation index

OMEGA. Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité

USGS. United States Geological Survey

VNIR. Visible–near-infrared