Volcanic and Tectonic History of the Nemesis Tessera Region on Venus

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Volcanic and Tectonic History of the Nemesis Tessera Region on Venus: SCIENTIFIC/TECHNICAL/MANAGEMENT SECTION

SCIENTIFIC OBJECTIVES

This proposal requests funding to support a new, three year, multi-faceted investigation of the geological relationships preserved in the Nemesis Tessera region of Venus. Specifically, my students and I will:

1. Unravel and assess in detail the complex volcanic and tectonic history of two giant radiating fracture systems (possibly dike swarms) which have formed in unusual geological settings—one is centered at the triple junction of a Y-shaped ridge belt while the focus of the other lies upon the rim of an unusual, corona-like fracture annulus.
2. Evaluate whether systematic variations in the dominant style of volcanism occur within the region as a function of time, and use the altitude distribution of volcanic features interpreted to be reservoir-derived to test the hypothesis that their formation is controlled in part by neutral buoyancy.
3. Characterize the origin and history of the regional stress field(s) by interpreting the distribution and relative timing of the diverse array of structural deformation preserved within the region.
4. Integrate the stress field and volcanic history interpretations within this lowland area in order to assist with ongoing efforts to constrain competing regional/global resurfacing models and test the controversial hypothesis that a global stratigraphic sequence exists on Venus.

NEMESIS TESSERA – GENERAL GEOLOGICAL SETTING AND SIGNIFICANCE

The Nemesis Tessera region (180-210°E, 25-50°N; hereafter referred to simply as Nemesis Tessera), which covers the central portion of Ganiki Planitia, is located northwest of the Beta-Atla Themis volcanic zone and southeast of the Atalanta Planitia lowlands, areas commonly interpreted to be the result of large scale mantle convection [e.g., *Bindschadler et al*., 1992; *Crumpler et al*., 1993; *Phillips and Hansen*, 1998]. The region immediately south of Nemesis Tessera is dominated by Atla Regio, a major volcanic rise beneath which localized upwelling appears to be ongoing [*Bindschadler et al*., 1992], while the area just to the north is dominated by the orderly system of compressional tectonic belts in Vinmara Planitia [*Zuber*, 1987]. Nemesis Tessera thus lies intermediate between several key regions where extensive, mantle-induced tectonic and volcanic activity has occurred, and careful analysis of the regional geology may provide new insight into the relative timing of and interaction between these significant, large scale, surface-shaping events.

Within Nemesis Tessera the geology is characterized by gently varying topography and a complex array of volcanic, tectonic and impact features which are generally surrounded by or superimposed upon a background of volcanic plains (Figure 1). Tectonic deformation has produced tessera, ridge belts and rifts as well as a distributed system of fractures and wrinkle ridges which extends throughout the region. Little is known about either the timing/stratigraphy of these tectonic features or the stress(es) which produced them; the latter, given Nemesis

Tessera's location relative to Atla Regio and Atalanta Planitia, are likely to be related to processes active both within and outside of the region, underscoring the need to interpret the geological record carefully and in detail.

Volcanic activity has also been quite intense. In addition to the extensive volcanic plains deposits, thirty-two major volcanic centers, including two calderas, three coronae, six large volcanoes, ten shield fields and eleven arachnoids were identified during a global survey based primarily upon C1-MIDR image interpretation [*Crumpler and Aubele*, 2000]. Most of these features were examined in only a cursory fashion, however, and therefore the details of their evolution and stratigraphic placement are not yet well constrained. Furthermore, since at least one major volcanic center was not detected by *Crumpler and Aubele*—an arachnoid with radiating fractures which extend hundreds of kilometers [*Grosfils and Head*, 1994b]—it is probable that other major centers remain to be found; indeed, new high resolution studies in other areas are revealing numerous, previously undetected volcanic centers at a variety of scales [*Ernst et al*., 2000]. It is also unclear how many small volcanic features such as individual shields and localized fissure eruptions exist within the region, and thus the importance of this style of volcanism relative to the activity which has occurred at the major centers remains poorly understood.

PROPOSED SCIENTIFIC ACTIVITIES

During the course of the proposed three year project, four related scientific questions will be addressed. Each of these is described in detail below.

Evaluate the Complex Volcanic and Tectonic History of Two Giant Radiating Fracture Systems.

The Nemesis Tessera region contains at least two giant radiating fracture systems which extend radially for hundreds of kilometers across the surrounding volcanic plains. Although some general information has been gathered for each, neither has been carefully studied. The first fracture system (40°N, 194°E) radiates away from the "triple junction" of a Y-shaped ridge belt located near the center of the Nemesis Tessera region (Figure 2). The fractures fan over approximately 300 degrees of arc, and the system is at least 450 km in radius. The topography at the focus of the system is a dome 140 km across and 1.3 km in height, upon which both radial lava flows and a 100 km diameter central caldera are superimposed. The second radiating fracture system (26°N, 207.5°E), located in the southeast portion of Nemesis Tessera, consists of fractures which fan through only 270 degrees of arc but extend at least 900 km from the center of the system (Figure 3). As with the first example, the central topography is a gentle dome upon which large radial lava flows are seen, but in this instance the diameter is 225 km while the height is only 250 m. The central focus of this system lies upon the northern edge of an unusual, double-ring fracture annulus some 225 km across. In spite of the association with a radiating fracture system and lava flows, this fracture annulus is not formally classified as a corona or other volcanic feature by *Crumpler and Aubele* [2000].

There are two basic endmember models for how a giant radiating fracture system can form. First, the extensional hoop stress generated when a mantle plume, diapir or similar body upwarps the crust into a dome can readily produce a radiating fracture system and centralized volcanism [e.g., *Stofan et al*., 1991; *Cyr and Melosh*, 1993]. The uplift origin of the stresses dictates, however, that the radiating fractures are unable to extend into or beyond the zones of strike slip faulting and annular compression which form at the edge of the dome as it grows and then relaxes [*Janes et al*., 1992]. This model is inconsistent with the geometry of the two known giant radiating fracture systems in Nemesis Tessera, where fractures extend from 300-700 km beyond the lateral extent of the gentle, central domical topography with which they are associated – i.e., the fracture system radii are ~4-7x the radius of the dome upon which they are centered.

The second model for how giant radiating fracture systems can form invokes shallow dikes radiating away from a central magma source [e.g., *Ode*, 1957; *Muller and Pollard*, 1977; *McKenzie et al*., 1992]; as with the uplift model, these conditions are also conducive to centralized volcanism. The fractures are produced when extensional stresses above each dike induce linear deformation at the surface, a process which has been clearly documented on Earth [e.g., *Mastin and Pollard*, 1988; *Rubin*, 1992]. Significantly, the length of the dikes and the fractures they generate is not limited by the presence, absence or lateral extent of any central domical topography. Instead, dike length is controlled principally by magma supply rate and thermal factors and thus, as observed for the Mackenzie swarm and other examples on Earth [*Ernst et al*., 1995], dikes can extend hundreds to thousand of kilometers independent of the size or presence of any central domical topography [*Parfitt and Head*, 1993; *Fialko and Rubin*, 1999]. To a first order, these predictions more cleanly match the observed characteristics of the radiating fracture systems observed in the Nemesis Tessera region [*Grosfils and Head*, 1994b].

Since dikes are discordant, rapidly emplaced [*Halls*, 1991] volcanic structures which adopt stress dependent geometries [*Anderson*, 1951], identification and careful study of laterally extensive dike systems can provide insight into the operation of both large scale magmatic and tectonic processes as well as regional stratigraphy. This makes them an ideal tool for studying several fundamental processes which affect the geologic evolution of a planetary surface. At present, however, very few features interpreted as dike swarms on Venus [*Grosfils and Head*, 1994b] have been studied in detail. Where examples have been examined carefully—northwest of Alpha Regio [*Grosfils and Head*, 1991], in Vinmara Planitia [*Grosfils and Head*, 1994a], southeast of Atla Regio [*Koenig and Pollard*, 1998] and in northern Guinevere Planitia [*Ernst et al*., 2000]—it appears that each radial system is the amalgamation of a complex sequence of intrusion, eruption and structural deformation events. Little is known thus far, however, about the conditions which promote development and evolution of these magmatic systems on Venus.

Careful mapping and further interpretation of the two putative dike swarms in Nemesis Tessera can tell us a great deal about how these complex radiating systems form and evolve, complementing what we have learned about this process from study of the heavily deformed and dissected swarms preserved on Earth. For instance, since large radiating dike swarms on Earth are commonly associated with mantle plume impingement and the development of Y-shaped rift settings and other extensional systems [*Fahrig*, 1987; *Ernst et al*., 1995], how did the Nemesis Tessera radiating systems form in what appear to be compressional annulus and ridge belt settings? Does this challenge the current interpretation that they are dike swarms, and if so (or not) what are the implications for how these vast radiating fracture systems formed and what does this tell us about the conditions under which similar systems might develop on Earth? In order to address these questions, it is critically important to examine the stratigraphy of the swarms themselves and in the context of their regional setting. Since only a handful of radiating fracture systems have been carefully examined thus far on Venus, detailed mapping of the two found in Nemesis Tessera has the potential to contribute substantially and perhaps in unexpected ways to our understanding of how these complex volcano-tectonic systems form and evolve.

Independent of what can be learned about the mechanics of dike swarm formation, and in fact independent of whether or not these features actually are dike swarms, there are two compelling arguments (within the broader framework of deciphering the geologic history in Nemesis Tessera) for why careful, detailed study of the radiating fracture systems is important. First, because individual dikes/fractures form rapidly in a geologic context, these structures serve as excellent stratigraphic markers across great distances. The better the timing of their formation is constrained—did the radiating fractures form all at once (i.e., do they record a single stress field, avoid cross-cutting one another, etc.), over an extended period, as several discrete fanning "subsystems" which crosscut one another, etc.—the more useful the fracture systems become for tying together the regional stratigraphy across large portions of Nemesis Tessera. Second, since the fracture alignments are stress-dependent, these features are useful for evaluating tectonic stress orientations. Again, the more carefully the timing of their formation is constrained the more useful the fracture systems become for evaluating the regional stress history.

<u>Characterize and Interpret the Regional Volcanic History.</u>

Plains Formation. Nemesis Tessera records what appears to be a complex volcanic evolution. A large part of the region is covered by volcanic plains, but these plains are not uniformly distributed and they exhibit broad differences in texture and radar brightness. Interpreting the stratigraphy of the region's different plains units and evaluating how they relate to other volcanic activity in the area is critically important to our understanding of the formation and geologic evolution of Nemesis Tessera. Specifically, is there a clear transition from plains-forming eruptions to localized, reservoir-derived eruptions, or is there a complex assembly of volcanic styles preserved as a function of time? This information will help constrain how volcanic resurfacing of the area was accomplished (see resurfacing section below).

Magma Stalling and General Volcanic Stratigraphy. While unraveling the history of the plains is a major objective, understanding the relative stratigraphy of other volcanic features preserved in the quadrangle is equally important—particularly those formed in association with magma reservoirs. The Nemesis Tessera region contains a variety of volcanic features which are likely to be reservoir-derived, including large volcanoes, potential radiating dike swarms, calderas and in all likelihood shield fields; there are essentially no volcanic features from which an absence of reservoirs would be inferred, with the possible exception of the three coronae. This suggests that magma stalling at shallow depth within the crust has contributed significantly to the volcanic evolution of Nemesis Tessera. What conditions are required to facilitate magma stalling? One proposal is that this process is governed by the development of shallow neutral buoyancy zones [*Head and Wilson*, 1992]. *Head and Wilson's* calculations predict that very few reservoir-derived volcanic features should develop below a planetary radius of 6051 km, and that reservoir depth and size should both increase as a function of altitude above this radius. This implies that a gradual transition from smaller to larger edifices and finally deeper-seated intrusive bodies (e.g., dike swarms, large calderas) should occur as a function of increasing elevation. These predictions are generally consistent with the distribution of the intermediate volcano [*Ristau et al*., 1998; *Krause and Grosfils*, 1999], large volcano [*Keddie and Head*, 1994] and dike swarm [*Grosfils and Head*, 1995] populations as a function of elevation, but large calderas have not been studied systematically and an ongoing global examination of the shield field population has thus far proved inconclusive [*Grosfils*, 1999].

Significantly, although several global-scale assessments of the neutral buoyancy hypothesis have occurred, no attempt has yet been made to test the model predictions for a single large area.

It is quite important for this type of test to be conducted so that the results can be interpreted within the framework of a firmly constrained volcanic stratigraphy. How does the agreement between model predictions and the observed altitude distribution of reservoir-derived volcanic features relate to the timing of these features' formation and any local/regional scale changes in topography, and what are the implications for global surveys which have thus far made no attempt to take these factors into account? To address these issues I will use the elevation distribution of all reservoir-derived volcanic features in Nemesis Tessera, coupled with interpretation of the volcanic stratigraphy, to continue testing the neutral buoyancy hypothesis for magma stalling and reservoir formation at shallow depth in the venusian crust. Nemesis Tessera is an ideal place to conduct this analysis due both to the high density of suitable reservoir-derived volcanic features as well as the variations in volcanic style and size observed.

<u>Characterize and Interpret the Regional Stress History.</u>

As is the case for the volcanic stratigraphy, evaluating the regional tectonic history will provide important insight into the formation and evolution of Nemesis Tessera, and thus the motivation for this portion of the proposed research is similar to that described above. The critical activity required to evaluate the stress history is careful mapping and interpretation of the sequence of structural deformation events. Principal stress directions can be inferred from the alignment of wrinkle ridges, fractures, rifts, ridge belts and the strain recorded by tessera. Analysis of the spatial and stratigraphic distribution of these features and the tectonic stress alignments they record will be used to evaluate whether changes in regional stress orientation occur as a function of time and if there are systematic differences in the way the stresses are accommodated. As an example of the latter, does distributed deformation which accommodates stresses at shallow depth via production of wrinkle ridges and fractures eventually give way to more concentrated deformation which produces ridge belts and rifts, does the opposite happen, or is the style of deformation which occurs time-independent? Characterizing the regional stress behavior will also provide insight into whether local stress-inducing or -perturbing features develop as a function of time, for instance in response to emplacement of a volcanic load. Ultimately, once it has been unraveled the stress history can be used to assess the scale and persistence of the regional stress fields in Nemesis Tessera, their relationship to mantle convection activities occurring outside the region (e.g., in Atla Region and Atalanta Planitia), and if/how the deformation is linked to any local or regional resurfacing process which occurs (see below).

<u>Test Resurfacing Models and Global Stratigraphy.</u>

As study of the region provides insight into the volcanic and tectonic evolution of Nemesis Tessera, the data which are gathered can also be used to assess general models for the formation and evolution of the existing geologic surface. There are two fundamental issues which will be addressed. First, is it likely that the current quadrangle formed during a large scale resurfacing event with minimal modification thereafter [e.g., *Parmentier and Hess*, 1992; *Arkani-Hamed et al.*, 1993; *Solomon*, 1993; *Turcotte*, 1993; *Herrick*, 1994], or is it the product of periodic, smaller scale resurfacing events [e.g., *Phillips et al.*, 1992; *Phillips and Hansen*, 1998; *Guest and Stofan*, 1999; *DeShon et al.*, 2000]? Even though the Magellan mission has been over for several years, the debate about the nature of the resurfacing process on Venus remains quite intense, and thus there is a continuing need to test the predictions of existing models via stratigraphic mapping. Second, does the regional sequence of events support the contention that there are global stratigraphic units [e.g., *Basilevsky and Head*, 1995; *Ivanov and Head*, 1998], or is there clear stratigraphic evidence that this is not the case [e.g., *Copp et al*., 1998; *Guest and Stofan*, 1999]?

Nemesis Tessera is an ideal location to examine both of these issues. First, it contains abundant plains and other volcanic features which can be used to evaluate the scale and timing of volcanic resurfacing directly, facilitating comparison with different resurfacing predictions. Second, there are abundant structural features from which the regional stress history may be inferred and related to the volcanic events. How does examination of these stress fields help constrain existing resurfacing models? The answer lies in constraining their relative age, scale and orientation. Are the stresses recording an older global scale field [e.g., *Grosfils and Head*, 1996; *Sandwell et al*., 1997], do they reflect younger regional scale activity such as lateral mantle flow between Atla Regio and Atalanta Planitia, or do they reflect primarily local tectonic activities acting over a long span of time? Third, most if not all of the global stratigraphic units proposed by *Basilevsky and Head* [1995] exist within Nemesis Tessera, and thus it will be possible to test the basic tenets of their stratigraphic sequence argument. It is thus clear that careful assessment of the volcanic and tectonic stratigraphy in the Nemesis Tessera region has the potential to contribute significantly to our ongoing efforts to understand how the current surface of Venus was formed.

RELEVANT PI EXPERIENCE

Research Activities

The proposed project and associated scientific objectives require (1) detailed interpretation of radiating fracture systems, including crosscutting relationships, stratigraphy, the interaction between volcanism and tectonism, relationship to topography, etc., (2) integration of image, topography and other remote sensing information to define accurate geological units, (3) evaluation of the regional volcanic and tectonic histories through detailed mapping and careful interpretation of stratigraphic relationships, and (4) integration of all these data to constrain models for resurfacing. These activities in Nemesis Tessera build upon and complement my previous experience studying volcanic and tectonic processes at local, regional and global scales on Venus. I have experience interpreting complex structural deformation in tessera terrain [e.g., *Grosfils and Head*, 1990], and most my time has been spent exploring the interplay between volcanism and tectonic deformation in different geological settings on Venus.

The bulk of my research efforts to date have focused upon understanding the process of giant radiating dike swarm emplacement on Venus, information which has also been used synergistically to improve our understanding of radial dike emplacement on Earth [*Ernst et al.,* 1995; *Ernst et al*., in prep]. At the global scale, I identified a population of 118 giant radiating dike swarms and used its characteristics to (1) constrain the configuration and origin of the global stress field [*Grosfils and Head*, 1994b], (2) explore mechanisms for magma stalling and reservoir formation at shallow depth within the venusian crust [*Grosfils and Head*, 1995], and (3) evaluate the relative age of the global stress field in order to constrain existing models for global resurfacing [*Grosfils and Head*, 1996]. Similarly, at a regional scale I have studied several giant radiating dike swarms. In Vinmara Planitia, for example, an area just north of Nemesis Tessera, I assessed a single swarm and its surroundings in detail in order to constrain the area's volcanic and tectonic stress history and refine our understanding of the regional stratigraphy [*Grosfils and Head*, 1994a]. Each of these projects involved integration of structural, volcanological and stratigraphic information as well as regional-scale mapping, and each set of results provided fresh insight into an important geologic problem with regional and/or global significance.

At present, in addition to continuing my studies of dike emplacement [e.g., *Ernst et al*., 2000], I am pursuing several other avenues of planetary research. These include (1) using other reservoir-derived volcanic features to continue assessing why magma stalls at shallow depth in the venusian crust [*Ristau et al*., 1998; *Grosfils*, 1999; *Krause and Grosfils*, 1999], (2) developing numerical models to study the mechanics of magma reservoir failure in order to assess the conditions which promote intrusion and eruption as well as the associated surface and subsurface deformation [*Grosfils and Head*, 1997], (3) using MOLA data and images to interpret the cratering record in the Arrhenius region of Mars [*Grosfils et al*., 2000a],and (4) refining our understanding of graben formation on the terrestrial planets via repeated geophysical surveys in Canyonlands National Park, Utah [*Bush et al*., 1996; *Moore et al*., 1997; *Grosfils et al*., 2000b].

<u>Undergraduate Planetary Research.</u>

Since beginning my position at Pomona College five years ago, I have worked closely with many sophomore, junior and senior undergraduates on a variety of planetary geology research problems. These interactions have been quite productive. Sixteen students (from eleven different undergraduate institutions) have explored volcanic and tectonic problems on Venus, and of these thirteen have thus far presented their results at a national conference [*Cook et al*., 1998; *Fletcher et al*., 1998; *King et al*., 1998; *Pike et al*., 1998; *Ristau et al*., 1998; *Krause and Grosfils*, 1999; *Jager and Grosfils*, 2000]. An additional eight students (from six different undergraduate institutions) have studied either the Moon or Mars, and of these six have thus far presented the results from their work at a national conference [*Foxx et al*., 1998; *Kraal et al*., 1998; *Thomson et al*., 1998; *Bradley et al*., 2000]. I have also involved four undergraduates (all from Pomona College) in planetary analog studies, predominantly in Canyonlands National Park, and all results from this work have been presented [*Bush et al.,* 1996; *Moore et al.,* 1997; *Grosfils et al*., 2000b]. In the summer of 2000 I will direct a 5-week undergraduate research project at the Goddard Space Flight Center, funded principally by the Keck Geology Consortium and NSF, during which ten sophomores will use Mars Global Surveyor and Viking data to assess the geology of a potential future landing site; I anticipate that most if not all of these students will present their findings at the next *Lunar & Planetary Science Conference*. Based on my past experiences, I expect there will be no difficulty involving Pomona College undergraduates directly and productively in the scientific investigation described in this proposal.

WORK PLAN

<u>*Overview*</u>. The research described in this proposal will be carried out primarily by the Principal Investigator. Portions of the project will involve work with undergraduates who will conduct their research in cooperation with and under the direct supervision of the PI each summer. During the academic year, it is likely that one or more students will focus their senior thesis research activity upon an issue related to assessment of the geology in Nemesis Tessera, but no funding is required to cover the cost of this assistance. In addition to working independently and with students, however, during the first one to two years the PI will work closely in collaboration with Dr. James R. Zimbelman. Dr. Zimbelman has participated extensively in the mapping programs for Venus and Mars, and thus his involvement will

contribute to the efficiency with which the regional stratigraphy is assessed during the first two years of scientific study in the Nemesis Tessera region. In addition, our interaction will facilitate careful study of how the 900 km long radiating dike swarm in Nemesis Tessera is related to a major tectonic feature with which it is connected in the adjacent Bellona Fossae (V15) quadrangle. I expect that the results of the scientific analysis and associated mapping will result in two journal articles (and will contribute to a third), a U.S. Geological Survey 1:5,000,000 scale Miscellaneous Investigations Series map of the Nemesis Tessera quadrangle (V14), and multiple conference presentations during the three year period for which funding is requested.

Year 1. The main science objectives during the first year will be to (1) study in detail the formation and evolution of the two giant radiating fracture systems found in Nemesis Tessera, and (2) assess whether a neutral buoyancy mechanism is consistent with the hypsometric distribution of all reservoir-derived volcanic features within the study area. My summer student will have primary responsibility for meeting the latter objective. The initial results from both science activities will be presented at a national conference such as AGU, GSA or LPSC, and I expect that the results from the neutral buoyancy analysis will get incorporated into a larger publication assessing the mechanics of magma stalling and reservoir formation on Venus.

During the first year, the PI will also construct an initial map of the stratigraphy and structural components in the Nemesis Tessera quadrangle. First order elucidation of structural and stratigraphic relationships through examination of Magellan FMAP images in both hardcopy and digital format will proceed using standard techniques (e.g., identification of superposition and crosscutting relationships, etc.). This preliminary map, prepared in ArcView, will provide a foundation for productive interaction with colleagues at the Venus Mappers meeting in Flagstaff—especially those working on adjacent quadrangles, namely Pondrosa Dorsa (McGill, done), Bellona Fossae (Zimbelman, in prep.), Atla Regio (Brackenridge, in prep.) and W. Ganiki Planitia (Head, in prep.)—and subsequent revision during the course of the following two years.

Year 2. The main science objectives during the second year, which I plan to pursue in association with one or two senior thesis students, will be to (1) interpret the volcanic history and assess whether volcanic style has changed as a function of time, and (2) carefully interpret the structural stratigraphy in order to assess the tectonic history within the quadrangle. I expect to submit the results from the radiating fracture system analysis to JGR-Planets or a similar venue for publication during the year, and the initial results from the volcanic and structural analyses will be presented at a national conference such as AGU, GSA or LPSC.

During the second year, the PI will also carefully reassess and revise the preliminary Nemesis Tessera map constructed during the previous year. Due to the inherent complexity of radar's interaction with a planetary surface, confident discrimination between units will almost certainly require systematic integration of additional remote sensing information such as surface roughness, emissivity and altimetry with the Magellan FMAPs [*Campbell*, 1995]. My summer student, who will already possess the necessary remote sensing skills, will assist with delineation of geologic units within the quadrangle by integrating the information contained in remote sensing data sets (e.g., surface roughness, emissivity, etc.) with the Magellan radar images and available stratigraphic data using a combination of ENVI and ArcView. This map will serve as the foundation for continued discussion with colleagues at the Venus Mapper's meeting in Flagstaff, which in turn will guide a final round of revision during the following year.

Year 3. The main science objective of the PI during the third year will be to integrate the volcanic and tectonic histories with the regional stratigraphy and material units in order to assess the implications for resurfacing within the quadrangle and how it relates to global, regional and local geologic activity; part of this analysis may be conducted in collaboration with a single senior thesis student. As a byproduct of this effort, I also expect to explore whether the stratigraphic sequence observed in Nemesis Tessera does or does not support the contentious global unit stratigraphy proposed by *Basilevsky and Head* [1995] on the basis of extensive mapping in other areas. I expect to submit a publication which combines the regional volcanic and tectonic history analyses with my assessment of the implications for resurfacing to JGR-Planets or a similar journal at the end of the third year.

In the third year, a summer student and I will also work together to clean up and finalize the Nemesis Tessera quadrangle mapping results in ArcView. The final map, a byproduct of the research effort described in this proposal, will be presented at a conference and then subsequently submitted at 1:5,000,000 scale to the U.S. Geological Survey for review and publication as part of the Miscellaneous Investigations Series.

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Volcanic and Tectonic History of the Nemesis Tessera Region on Venus:

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BROWN UNIVERSITY (1989 - 1995) <NSF Graduate Fellowship, 1990-1993> Providence, RI

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COLLEGE OF WILLIAM AND MARY (1984 - 1989) Williamsburg, VA

Sc.B. Physics (High Honors) & Geology. May, 1989.

POMONA COLLEGE ASSISTANT PROFESSOR (1995 — present)

Honors, Awards and Funding

- "Environmental Geochemistry and Hydrology of the Payette Lake Watershed, Idaho" (Co-I), a proposal funded by the Keck Geology Consortium, 1995-1996.
- "Seismic Study of Grabens in Canyonlands National Park" (PI), a proposal funded by the Summer Undergraduate Research Project program at Pomona College, 1996, 1999.
- Dwornik Prize (Hon. Mention) from the Geological Society of America , 1996.
- "Volcanism and Tectonics on Earth, Venus and Mars: A Planetological Approach" (PI), a proposal funded by the Keck Geology Consortium, 1996-1997.
- NASA-ASEE Summer Faculty Fellowship (AVIRIS), Jet Propulsion Laboratory, 1998.
- Smithsonian Institution Short Term Visitor appointment, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 1998.
- Jet Propulsion Laboratory Part Time Faculty appointment to assist with preliminary geological analyses and landing site selection for NASA's Mars Surveyor 2001 mission, 1998-1999.
- "Mars 2000" (PI), a proposal funded by the Keck Geology Consortium, 1999-2000.
- NASA-ASEE Summer Faculty Fellowship (MOLA), Goddard Space Flight Center, 1999.
- "Interactive research modules: A dynamic approach to remote sensing instruction" (PI), a proposal funded by the Mellon Project of the Claremont Colleges, 1997.
- "The astronomical and planetary image library" (Co-I), a proposal funded by the Mellon Project of the Claremont Colleges, 1997.
- NASA MDAP, "Analysis of Small Magma Reservoirs on Mars" (PI), 3 yrs, 10/2000 start.
- Have acquired (n=30) or helped to acquire (n=12) summer research funding for 42 undergraduates, with every research project culminating in at least one conference presentation, 1995-present.

Highlights of Recent Service to the Professional Community

- Pomona College's representative to the Keck Geology Consortium, 1996-present.
- Elected to "Faculty for the 21st Century," part of Project Kaleidoscope, 1997-present.
- Member of NASA's Discovery Mission proposal science review panel, 1998.
- Elected to Advisory Board (fundraising strategy team), Keck Geology Consortium, 1998-present.
- Active member of AGU, GSA, CUR, NAGT, PKAL and Sigma Xi.

+ 1 page on up-to-date list of relevant publications/abstracts