9-9-2010

Collaborative Research: ST. Elias Erosion/tectonics Project (STEEP)

Peter O. Koons
Principal Investigator; University of Maine, Orono, peter.koons@maine.edu

Final Report for Period: 09/2009 - 08/2010
Submitted on: 09/09/2010
Principal Investigator: Koons, Peter O.
Award ID: 0409162
Organization: University of Maine
Submitted By:
Koons, Peter - Principal Investigator
Title:
Collaborative Research: ST. Elias Erosion/tectonics Project (STEEP)

Project Participants

Senior Personnel

Name: Koons, Peter

Worked for more than 160 Hours: Yes

Contribution to Project:

Koons has overall direction of the modeling component of the STEEP project.

During the past 12 months, Koons has defined the nature of strain partitioning at a plate corner for sperically homogeneous and strain-dependent rheologies, identified the characteristic signal of plate corners from the early stages as identified in Alaska to the more evolved plate boundaries of SE Tibet, and worked to identify the relationship of thermal weakening to erosion concentration in SE Alaska.

Name: Upton, Phaedra

Worked for more than 160 Hours: Yes

Contribution to Project:

With the no-cost extension, we shifted Upton's last monthly contribution into this year. We had planned that Upton's modeling effort would be part of the last year's effort, after the completion of the GPS campaigns. Because of our no-cost extension requst to accommodate the weather-delayed GPS campaigns, we have postponed Upton's major modeling contribution to this extended year rather than this past year.

Post-doc

Graduate Student

Name: Hooks, Benjamin

Worked for more than 160 Hours: No

Contribution to Project:

Hooks submitted and was granted his PHD in September of 2009. Although he has been productive in publishing and developing software related to the STEEP project, he has not been funded by this grant. Below are some of activities in which he continues to participate:

Determining the influence of glacial erosional centers on the mechanical and thermal structure of the STEEP region via simulataneous solution for the 3d thermal and mechanical fields acted upon by various erosional schemes.

Evaluation of stress contribution from 3 D topography to regional stress and strain distribution.

Solution that employs strain weakening constitutive relations

Fieldwork (A. Barker) From June 26th to ~August 1st, 2006); Structural mapping in the Samovar Hills region with specific emphasis on:
a. Measurement of strain concentration spatially associated with regions of high glacial ice flux
b. Identifying the strain regimes related to the spatial splitting from predominantly strikeslip displacement to the south to predominantly shortening displacement to the north.
c. Aiding with the establishment of seismic stations in remote regions.

Name: Birkel, Sean

Worked for more than 160 Hours: No

Contribution to Project:

Helped with Ice Sheet Model coupled with Climate model.

Name: Perry, Randall

Worked for more than 160 Hours: No

Contribution to Project:

Numerical Modeling and investigation of geochemical/physical evolution of earth surface following deglaciation.

Undergraduate Student

Name: Wilson, Lee

Worked for more than 160 Hours: No

Contribution to Project:

Ran numenrical experiments and helped with visualisation in the Numerical Facility.

Name: Beebe, Calvin

Worked for more than 160 Hours: No

Contribution to Project:

Ran numenrical experiments and helped with visualisation in the Numerical Facility.

Name: Leber, Greta

Worked for more than 160 Hours: No

Contribution to Project:

Ran numenrical experiments and helped with visualisation in the Numerical Facility. Some Programing.

Name: Campbell, Seth

Worked for more than 160 Hours: No

Contribution to Project:

Ran numenrical experiments and helped with visualisation in the Numerical Facility.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

University of Texas El Paso

University of Washington

Lehigh University

University of Texas at Austin

University of Alaska Geophysical Institute

Indiana University

In charge of passive seismic experiment

University of Utah

Ron Bruhn and colleagues are providing structural and petrological coverage for the STEEP project, developing the longer term strain evolution of south east Alaska for comparison with the recent state.

Purdue University

With K. Ridgeway as PI, the Purdue team has investigated the sedimentological/ tectonic aspects of Yakutat terrain.

Other Collaborators or Contacts

Project participants:
In the first year of STEEP, Koons was the sole funded participant from the University of Maine.

In subsequent years, Upton (Post Doc) and Barker (graduate student), and Hooks have actively been modeliing the 3D thermal and mechancial evolution of the orogen as well as investigating the general relationships of deformation, erosion and the geochronological signal.
During the past two years, undergraduate and graduate students have worked on aspects of the project by running experiments, preparing graphics and, in some instances, investigating the atmosphere : solid earth coupling that is related to deglaciation.

Other collaborators are listed below.

Other organizations that have participated with me are: BLM who operate the Research operation at Bering Glacier, Alaska.

Institutions, participants and their responsibilities in the STEEP project are:

UT El Paso: Pavlis and Sherpa have recently moved to the University of Texas at El Paso where they are carrying out the responsibilities listed above
UTIG: Mann, Gulick, and Christenson will be responsible for logistical coordination and completion of the offshore seismic work and Van Avendonk will be responsible for onshore work that is part of that effort; the UTIG group will jointly work on data processing, and data release. Christenson will coordinate outreach efforts by this group.
Univ. Alaska F: Hansen will be responsible for logistics and broadband station installation (with G. Pavlis) and Freymueller will be responsible for coordinating GPS field efforts, data reduction, modeling, and data release.
Univ. of Washington: Hallet will coordinate the glaciology studies; Roe will determine the climate forcing used in the glacier modeling on various time scales. Stewart will be responsible for Apatite fission track work.
Univ of Utah: Bruhn will conduct geologic field studies, with particular emphasis on Quaternary studies
(collaborative with McCalpin), work with a student and T. Pavlis on LIDAR data manipulation and visualization, and field structural studies.
Purdue: Ridgway will work on field geologic studies and completion of sedimentary geology studies
Indiana Univ. G. Pavlis will work with U. Alaska in broadband station placement and data processing from the passive array and implementation of new earthquake location techniques.
Univ. Maine: Koons will be responsible for development of geodynamic modeling.
Virginia Tech: Spotila will be responsible for Apatite U-Th/He dating and analysis
Lehigh Univ.: Zeitler will be responsible for Ar/Ar thermochronology and dating, and Zircon U-Th/He dating.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

In the attached PDF file are summarized our research and education objectives. During the past year I have pursued these objectives in several ways:
STEEP annual report 2010 Koons
Major research and education activities Koons, Upton, Hooks
This past year has been part of the requested no-cost extension during which Upton received salary support, Hooks completed his PhD and moved to the University of Texas El Paso, and Koons did not receive salary support. Previous partial or complete support by the STEEP grant

of graduate students at the University of Maine (Birkel; PhD; Pingree MSc) led to continued contribution in scientific research and outreach.

During the past year we have concentrated on two main directions of research and education in modeling the evolution of southern Alaska and the physics of landscape evolution in 3D deforming plate boundary corners, visualisation of global climate and topography at high resolution, and thermal; chronological modeling of southern Alaska.

1) Koons and Upton have developed and submitted an alternative physical framework for landscape evolution that describes erosion within the same stress:strain framework as theearth deformation equations rather than within the potential field framework currently widely used. The solutions using analytical and numerical techniques were produced at UMaine and New Zealand using the software and hardware provided by the STEEP to UMaine's Numerical Facility for Geodynamics. Collaboration with UWashington's B. Hallet and A. Barker has led to an evaluation of the geomorphic expression of material anisotropy . Upton is further expanding this theory at Edinburgh University and with Koons at UMaine in September of 2010.

2) S. Birkel, partially supported by STEEP and undergraduate research assistants working with Koons have completed and tested a web-available visualisation structure to be used in research and teaching that permits interrogation of global climate at resolution, generally, of < 5 km. This has been partially funded by ITEST-IDEAS (Koons, co-PI), and has been tested in teacher workshops as well as in simple climate modeling.

Koons has been involved in each of the modeling directions.

Findings: (See PDF version submitted by PI at the end of the report)

(SEE ATTACHED FILE for graphics)

TEEP annual report 2010 Koons

Major Findings Koons, Upton

In actively deforming orogens, the material strength at the earth surface is controlled in part by strain localization determined by the local stress fields which in turn are driven by contributions from local topography and far field plate velocities. Material weakening associated with strain localization imparts partially predictable, and entirely inescapable heterogeneity to the material fabric of an orogen. The characteristic damage structure of individual fault zones that undergo strain weakening, as imaged in dam site excavations, deep drill holes and geological observations, results in geomorphically relevant strength variations normal to the fault of many orders of magnitude. The sensitivity of both hillslope and fluvial erosion to the strength parameters coupled with the large and oriented strain-related strength variations, causes the topographic evolution to be dominated by tectonically driven rheological behavior at multiple wavelengths. Using three-dimensional, lithospheric scale modeling of two oblique orogens, Southern Alps, New Zealand and the Eastern Himalayan Syntaxis, we examine the generation of a model surface strength field that occurs as a consequence of a simple strain softening upper crustal rheological model. Mapping of topographic anisotropy of the Southern Alps and the Eastern Himalaya Syntaxis indicates azimuthal control on correlation distances that are spatially related to the different strain regimes of the two orogens similar to what we predict in a similar tectonic setting of southern Alaska. By defining landscape evolution in terms of mechanical failure in the conventional motion: stress mechanical framework, the behavior of the earth surface can be brought into the same theoretical framework as the behavior of the sub-surface and many of the observational:theoretical inconsistencies arising from application of dominantly potential field theory can be obviated. Heterogeneity and anisotropy of material strength are fundamental aspects of active orogens and description of the strength field in terms of mechanical evolution can significantly extend present earth surface models.

Training and Development:

Opportunities for training, development and mentoring

In the NSF-funded Numerical Facility for Geodynamics we involve undergraduate and , graduate students in continuum mechanical modeling as part of formal course work (e.g. ERS 602; Fluid Dynamics; ERS 316; Structural Geology; and ERS 317; Introduction to Geophysics) as well as part of research opportunities in thesis research. STEEP-funded software was used in introduction to finite element instruction at graduate level (ERS 602) B. Hooks will return, together with P Upton, for an informal STEEP modeling workshop (September 2010). We employ several undergraduate students on funds from this grant to participate in modeling and visualization. One REU student worked with our STEEP-funded numerical facility during the summer of 2010 on visualisation of mechanical results and climate modeling.

Outreach Activities:

Outreach activities
Our current modeling effort for STEEP has provided basic teaching material for University of Maine Earth Science curriculum in courses including:
ERS 200; ERS 316; ERS 317; ERS 602 .
STEEP material forms the scientific examples for the NSF funded ITEST program for k12 teachers in which Koons has spent ~ 30 contact hours during the past 12 months of seminars, demonstrations and curriculum development. This program has involved ~ 20 teachers per year in 15 workshops and introduced these teachers to curricula material derived from results of the STEEP project.

Much of the modeling material and results are available to a larger audience through the websites:
http://www.geology.um.maine.edu/geodynamics/Numerical/projects.html
http://www.geology.um.maine.edu/geodynamics/AnalogWebsite/html_files/crustal%20dynamics.html

We encourage K12 participation in our geodynamic facility as well as use of our results and visualisation material in k12 courses.

Journal Publications

Perry, R; Norton, S; Koons, P, "Comparison of laboratory and whole-ecosystem weathering in early post-glacial environments", GEOCHIMICA ET COSMOCHIMICA ACTA, p. A738, vol. 72, (2008). Published,

Groome, WG; Koons, PO; Johnson, SE, "Metamorphism, transient mid-crustal rheology, strain localization and the exhumation of high-grade metamorphic rocks", TECTONICS, p. , vol. 27, (2008). Published, 10.1029/2006TC00199

Berger, AL; Gulick, SPS; Spotila, JA; Upton, P; Jaeger, JM; Chapman, JB; Worthington, LA; Pavlis, TL; Ridgway, KD; Willems, BA; McAleer, RJ, "Quaternary tectonic response to intensified glacial erosion in an orogenic wedge", NATURE GEOSCIENCE, p. 793, vol. 1, (2008). Published, 10.1038/ngeo33

Upton, P., P. O. Koons, D. Craw, M. Henderson, and R. L. Enlow, "Along strike differences in the Southern Alps of New Zealand: Consequences of inherited variation in rheology,", TECTONICS, p. , vol. , (2009). Published, doi:10.1029/2008TC002353,

Johnson, S.E., Lenferink, H.J., Marsh, J.H., Price, N.A., Koons, P.O. and West, D.P., Jr.,, "Kinematic vorticity analysis and evolving strength of mylonitic shear zones: new data and numerical results.", Geology, p. , vol. , (2009). Accepted,

Koons, P.O. Hooks, B., Barker, A.D. Upton, P.O., Pavlis, T.,, "Three-dimensional deformation of the southeastern Alaskan Plate Boundary", TECTONICS, p. , vol. , (2009). Submitted,

Koons, P.O.,, "On the implications of low spatial correlation of tectonic and climate variables in the western European Alps,", GEOLOGY, p. , vol. 37, (2009). Published,

Koons, P. O., B. P. Hooks, T. Pavlis, P. Upton, and A. Barker, "Three-dimensional mechanics of Yakutat convergence in the southern Alaskan plate corner", TECTONICS, p. , vol. , (2010). Published, doi:10.1029/2009TC002463

Koons, P.O., P. Upton, A.D. Barker, "The influence of mechanical properties on the link between tectonic and topographic evolution.", GEOMORPHOLOGY, p. , vol. 120, (2010). Submitted,

Johnson, S.E., Jin, Z.-H., Naus-Thijssen, F.M.J. and Koons, P.O.,, "Coupled deformation and metamorphism in the roof of a tabular mid-crustal igneous complex", Bulletin of the Geological Society of America, p. , vol. , (2010). Accepted,

Naus-Thijssen, F.M.J., Johnson, S.E. and Koons, P.O.,, " Modeling crenulation cleavage: a polymineralic approach.", Journal of Structural Geology, p. , vol. 32, (2010). Accepted, 10.1016/ j.jsg.2010.01.004

Enkelmann, E., P.K. Zeitler, J.I. Garver, T.L. Pavlis, and B.P.Hooks, "The thermochronological record of tectonic and surface process interaction at the Yakutat-North American collision zone in southeast Alaska", American Journal of Science,, p. , vol. 310, (2010). Published,

Books or Other One-time Publications

Birkel, S. D., Koons, P. O., Pingree, K. A., Segee, B. E., Zhu, Y., Schauffler, M., "Simple Climate Model and Web Interface for Inquiry-Based Learning at Middle and High School Grade Levels.", (2009). abstract, Published
Bibliography: Eos Trans. AGU, 90(54), Fall Meet. Suppl., (Fall Meeting 2009)

Hooks, Benjamin P., Eva Enkelmann, Peter O. Koons, and Phaedra Upton,, "Exploring Ice Sheets and Climate Change through Modeling of the St. Elias Tectonic Aneurysm", (2009). abstract, Published
Bibliography: Geological Society of America, Abstract with Programs, v. 41, no. 7, p. 305.

Hooks, Benjamin P., Peter Koons, and Phaedra Upton,, "Modern tectonics of southern Alaska and implications to the Acadian Orogeny,", (2009). abstract, Published
Bibliography: Geological Society of America, Abstract with Programs, v. 41, no. 3, p. 29.

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

Contributions
The new description of surface evolution in terms of newtonian stress:strain mechanics that has formed much of the material for research over the past year permits a far simpler linking of atmospheric and silicate earth evolution in South East Alaska. Linking surface evolution to the 3D deformation of the Yakutat block can now be done within the same physical framework in which material failure related to erosion is conditioned by the same stresses as those responsible for earth deformation. We have developed the theory such that fluvial and glacial erosion, slope failure and earth deformation are all operating with the same set of time-dependent material laws. This new formulation avoids many of the incompatibilities between theory and observation that have arisen in the prevailing, slope-defined landscape evolution paradigm.

Modeling of Yakutat collision has contributed to an understanding of the growth of two coupled orogens as a characteristic of the early stages of convergence, rather than a single critical orogen.

In addition, the relative importance of erosion and the tectonic geometry has been resolved in the initial formation of the positive feedback characteristic of tectonic aneurysm. In southern Alaska, erosion and topography modify a pattern dominated by the tectonic conditions.

Contributions to Other Disciplines:

Our modeling of evolving topography has contributed to an understanding of orographic influence on North American climate patterns and hemispheric circulation patterns as seen in ice core climate records.

Contributions to Human Resource Development:

Our visualization developments and climate:tectonic interaction work has directly led to the use of supercomputers in schools through the Maine Laptop Initiative (see: http://arch.eece.maine.edu/ideas/index.php/Main_Page).

Funding from this grant has permitted numerous undergraduate and graduate students at the University of Maine to become familiar with tools for numerical exploration of continuum mechanics relevant to teconic and climate processes.

Contributions to Resources for Research and Education:

Using the dynamic phenomena investigated in the STEEP project, i.e. glaciation, earthquakes and climate, we have been able to alter our teaching curriculum so that topics such as fluid mechanics, structural geology and geomorphology are placed in a modern, visible context. We are now in the process of producing educational modules that use this context to reach K12 levels as well as undergraduates at the University of Maine. We anticipate that our approach could have widespread applicability as we develop it further.

Contributions Beyond Science and Engineering:

Conference Proceedings

Perry, R;Norton, S;Koons, P, Comparison of laboratory and whole-ecosystem weathering in early post-glacial environments, "JUL, 2008", GEOCHIMICA ET COSMOCHIMICA ACTA, 72 (12): A738-A738 Suppl. 1 JUL 2008

Categories for which nothing is reported:

Any Web/Internet Site

Any Product

Contributions: To Any Beyond Science and Engineering

STEEP annual report 2010 Koons

Major research and education activities Koons, Upton, Hooks

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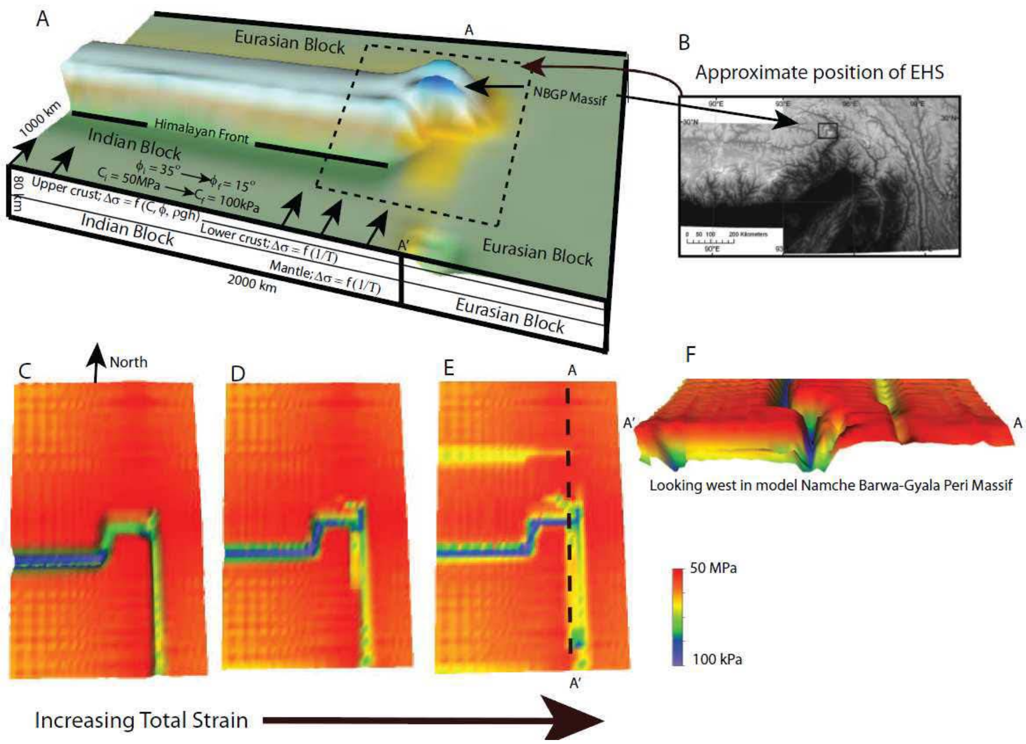
Koons has been involved in each of the modeling directions.

STEEP annual report 2010 Koons

Major Findings Koons, Upton

In actively deforming orogens, the material strength at the earth surface is controlled in part by strain localization determined by the local stress fields which in turn are driven by contributions from local topography and far field plate velocities. Material weakening associated with strain localization imparts partially predictable, and entirely inescapable heterogeneity to the material fabric of an orogen. The characteristic damage structure of individual fault zones that undergo strain weakening, as imaged in dam site excavations, deep drill holes and geological observations, results in geomorphically relevant strength variations normal to the fault of many orders of magnitude. The sensitivity of both hillslope and fluvial erosion to the strength parameters coupled with the large and oriented strain-related strength variations, causes the topographic evolution to be dominated by tectonically driven rheological behavior at multiple wavelengths. Using three-dimensional, lithospheric scale modeling of two oblique orogens, Southern Alps, New Zealand and the Eastern Himalayan Syntaxis, we examine the generation of a model surface strength field that occurs as a consequence of a simple strain softening upper crustal rheological model. Mapping of topographic anisotropy of the Southern Alps and the Eastern Himalaya Syntaxis indicates azimuthal control on correlation distances that are spatially related to the different strain regimes of the two orogens similar to what we predict in a similar tectonic setting of southern Alaska. By defining landscape evolution in terms of mechanical failure in the conventional motion: stress mechanical framework, the behavior of the earth surface can be brought into the same theoretical framework as the behavior of the sub-surface and many of the observational:theoretical inconsistencies arising from application of dominantly potential field theory can be obviated. Heterogeneity and anisotropy of material strength are fundamental aspects of active orogens and description of the strength field in terms of mechanical evolution can significantly extend present earth surface models.



Example of the application of alternative landscape evolution to one plate boundary corner. Evolution of the surface strength field for the corner environment of the Eastern Himalayan Syntaxis 3D model (*EHSlm*). The basic lithospheric model (A) represented by the vertical displacement surface (Blue = 8km; green = 0) derives from previously published work with strain softening rule imposed on the upper crust. Relief map of the EHS (B) covers approximately the same region as the expanded cohesion maps (C, D, E and F). In C, D, E and F red is intact rock (C = 50MPa, ϕ_i = 35^o), blue is softened rock mass to 100kPa; $\phi_f = 15^o$ at >3% shear strain. F depicts a view of model cohesion structure of E looking west from the eastern edge of the NBGP massif. The theory is currently being extended to the landscape evolution in south east Alaska under glacial erosion conditions in collaboration with the STEEP researchers at the University of Washington.

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including:
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We encourage K12 participation in our geodynamic facility as well as use of our results and visualisation material in k12 courses.

Journal Publications (research partly or entirely funded by STEEP 2009-2010 to Koons)

Koons, P.O., 2009, On the implications of low spatial correlation of tectonic and climate variables in the western European Alps, GEOLOGY, 37, 863-864

Koons, P. O., B. P. Hooks, T. Pavlis, P. Upton, and A. Barker, 2010, Three-dimensional mechanics of Yakutat convergence in the southern Alaskan plate corner, Tectonics, doi:10.1029/2009TC002463,

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Naus-Thijssen, F.M.J., Johnson, S.E. and Koons, P.O., 2010. Modeling crenulation cleavage: a polymineralic approach. Journal of Structural Geology, 32, 330-341, doi: 10.1016/ j.jsg.2010.01.004.

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Pingree, K.A., Koons, P.O., Birkel, S.D., Segee, B., Zhu, Y., and Schauffler, M. (2009), Exploring Ice Sheets and Climate Change through Supercomputer Visualizations in Middle and Secondary Schools, *Eos Trans. AGU, 90*(54), Fall Meet. Suppl., Abstract submitted, 09/2009.

Hooks, Benjamin P., Eva Enkelmann, Peter O. Koons, and Phaedra Upton, 2009, 3D Thermomechanical Modeling of the St. Elias Tectonic Aneurysm, Geological Society of America, Abstract with Programs, v. 41, no. 7, p. 305.

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Hooks, B.P., E. Enkelmann, P.O Koons, P. Upton, and T.L. Pavlis, in preparation, 3D Mechanical View of the Relative Importance of Surface and Tectonic Processes in the Initiation of the St. Elias Tectonic Aneurysm, for submission to EPSL.

Hooks, B.P., and B.R. Smith-Konter, 2010, 3D numerical mechanical modeling of the southern San Andreas Fault system, 2010 Workshop on Crustal Deformation Modeling, sponsored by Southern California Earthquake Center and Computational Infrastructure for Geodynamics, Golden, CO. 18 June 2010.

Hooks, B.P., 2010, Geodynamics of Terrane Accretion in southern Alaska, University of Texas at El Paso, Graduate Seminar, 18 February 2010

Contributions

The new description of surface evolution in terms of newtonian stress:strain mechanics that has formed much of the material for research over the past year permits a far simpler linking of atmospheric and silicate earth evolution in South East Alaska. Linking surface evolution to the 3D deformation of the Yakutat block can now be done within the same physical framework in which material failure related to erosion is conditioned by the same stresses as those responsible for earth deformation. We have developed the theory such that fluvial and glacial erosion, slope failure and earth deformation are all operating with the same set of time-dependent material laws. This new formulation avoids many of the incompatibilities between theory and observation that have arisen in the prevailing, slope-defined landscape evolution paradigm.

STEEP annual report 2010 Koons

Major Findings Koons, Upton

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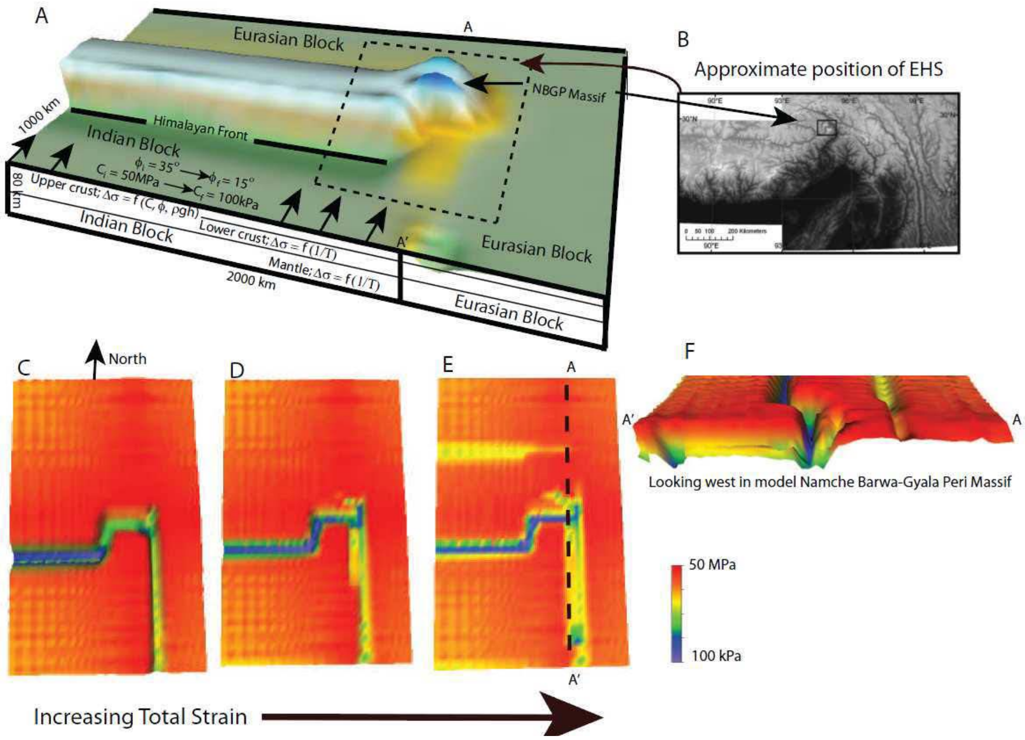

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STEEP annual report 2010 Koons

Major research and education activities Koons, Upton, Hooks

This past year has been part of the requested no-cost extension during which Upton received salary support, Hooks completed his PhD and moved to the University of Texas El Paso, and Koons did not receive salary support. Previous partial or complete support by the STEEP grant of graduate students at the University of Maine (Birkel; PhD; Pingree MSc) led to continued contribution in scientific research and outreach.

During the past year we have concentrated on two main directions of research and education in modeling the evolution of southern Alaska and the physics of landscape evolution in 3D deforming plate boundary corners, visualisation of global climate and topography at high resolution, and thermal; chronological modeling of southern Alaska.

1) Koons and Upton have developed and submitted an alternative physical framework for landscape evolution that describes erosion within the same stress:strain framework as theearth deformation equations rather than within the potential field framework currently widely used. The solutions using analytical and numerical techniques were produced at UMaine and New Zealand using the software and hardware provided by the STEEP to UMaine's *Numerical Facility for Geodynamics.* Collaboration with UWashington's B. Hallet and A. Barker has led to an evaluation of the geomorphic expression of material anisotropy . Upton is further expanding this theory at Edinburgh University and with Koons at UMaine in September of 2010.

2) S. Birkel, partially supported by STEEP and undergraduate research assistants working with Koons have completed and tested a web-available visualisation structure to be used in research and teaching that permits interrogation of global climate at resolution, generally, of < 5 km. This has been partially funded by ITEST-IDEAS (Koons, co-PI), and has been tested in teacher workshops as well as in simple climate modeling.

Koons has been involved in each of the modeling directions.