# Aegean **Symposium**

Güllük,TURKEY

## SESSIONS

- GEOLOGY OF THE AEGEAN
  Talks are geared towards both general overviews and discussions about specific domains within the Aegean region.
- GEOARCHEOLOGY, NATURAL HISTORY AND HAZARDS
  Volcanic explosions, hominid migration, earthquake hazards, links between human affairs and geology.
- DYNAMIC PROCESSES
  Includes discussions about large-scale crustal extension, orogenic collapse, subduction zones, seismic activity.
- COMPARISONS
  How is Aegean geology similar to places elsewhere on the planet?

Donald D. Harrington-Symposium on the Geology of the Aegean.

April 28-30, 2008

Jackson School
Geosciences

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WWW.JSG.UTEXAS.EDU/HARRINGTON_SYMPOSIUM

Donald D. Harrington Symposium

The University of Texas at Austin
Jackson School of Geosciences
1 University Station C1100
Austin, TX 78712-2054
www.jsg.utexas.edu/harrington_symposium

# Geology of the Aegean

*April 28-30, 2008*

## Welcome

Welcome to the Donald D. Harrington Geology of the Aegean Symposium. The Donald D. Harrington Fellows program is the most prestigious fellowship program at the University of Texas at Austin. The program was created by Sybil B. Harrington as a tribute to her husband, Donald D. Harrington. She envisioned a program that would support gifted and ambitious young scholars of all disciplines at the University of Texas at Austin with the support and prestige of programs such as the Fulbright Scholars and Guggenheim Fellowships. Don Harrington was born in Illinois in 1899 and moved westward after serving in the Army Air Corps during World War I. Mr. Harrington took a position as a landman with Marlin Oil Company in Oklahoma. When the Texas Panhandle oil boom hit in 1926, he moved to Amarillo, Texas, where he met Sybil Buckingham—the granddaughter of one of Amarillo's founding families. They married in 1935 and went on to build one of the most successful independent oil and gas operations in Texas history. The couple created the Don and Sybil Harrington Foundation in 1951 to support worthy causes such as museums, medical research, education, and the arts. The Harrington legacy of philanthropy is far-reaching. The University of Texas at Austin is privileged to be the home of this preeminent program.

This is the first ever Harrington Symposium geared towards the Geology of the Aegean. The program covers a range of investigations, including overviews of Aegean geology, dynamic models, volcanic processes and effects, links between geology and archeology, and comparisons of the Aegean to regions elsewhere. We welcome our international participants, and hope to establish new partnerships and collaborations. We also welcome teachers from the state of Texas, who will be provided with an opportunity to see the interdisciplinary nature and international flavor of Earth Science.

**SPECIAL ACKNOWLEDGEMENTS FOR ADDITIONAL SUPPORT FROM**
- Edwin Allday Lectureship in Geological Sciences
- Virgil E. and Mildred L. Barnes Distinguished Lecture Series in Geology
- Robert H. Cuyler Endowed Lecture Series Cynthia S. Oualline Centennial Lectureship in Geological Sciences
- Fred L. and Frances J. Oliver Lectureship in Texas Hydrology and Water Resources
- Getty Oil Company Centennial Chair in Geological Sciences
- American Association of Petroleum Geology
- University of Texas at Austin, Jackson School of Geosciences

# Endowed Lectureships

**Virgil E. and Mildred L. Barnes Distinguished Lecture Series in Geology.** Virgil E. Barnes, Professor Emeritus of Geological Sciences, former Associate Director of the Bureau of Economic Geology, was one of the world's leading experts on the geological phenomena of tektites. He was at the University of Texas at Austin for 63 years, and was professionally active until the time of his death in 1998. Born June 11, 1903, in Chehalis, Washington, Barnes earned his B.S. and M.S. degrees in geology at Washington State College (now Washington State University) and his Ph.D. in geology at the University of Wisconsin in 1930. Immediately after finishing his doctorate, he worked for the American Petroleum Institute in Austin and later for the U.S. Geological Survey in Amarillo, Texas. He joined the University's Bureau of Economic Geology in 1935.

**Robert H. Cuyler Endowed Lecture Series.** The Robert H. Cuyler Lecture Series was created by the estate of Benjamin M. Anderson to honor his friend, Captain Robert Hamilton Cuyler. Robert Cuyler was born in Austin, Texas on May 28, 1908 and was Associate Professor of Geology at the University of Texas at Austin for 17 years. His untimely death, in the prime of his career in 1944, was a staggering blow not only to his friends and family, but to the science of geology, specifically micropaleontology and subsurface geology.

**Edwin Allday Lectureship in Geological Sciences.** The Edwin Allday lectureship was established in 1982 from the estate of Edwin Allday to support visiting lecturers in geological sciences. Born in 1929, Edwin Allday was an independent oil and gas operator in Houston, Texas. He also had cattle and ranching operations in Red River and Houston Counties, Texas. Allday attended the University of Houston in 1948, then received a BS in geology in 1951 and his Masters in geology in 1953.

**Fred L. and Frances J. Oliver Lectureship in Texas Hydrology and Water Resources.** Fred and Frances Oliver created this lectureship in 1985 because they believe the study of water resources in Texas is as important as the development and exploration of oil and gas. They established the lectureship with the goal of providing better education concerning water problems being faced by Texas and solutions to those problems. Fred received his B.S. in geology from the University of Texas at Austin in 1951. He is a current member of the Geology Foundation Advisory Council. Fred and Frances reside in Dallas, Texas where Fred is the president of PVT, Inc.

**Judd and Cynthia S. Oualline Centennial Lectureship in Geological Sciences.** Judd was born on October 24, 1920 in Conroe Texas. He graduated from the University of Texas at Austin in 1942 with a Bachelor degree in Geology. He served as a First Lieutenant in the United States Army Air Corps during World War II. Judd had a distinguished career in the oil industry which concluded with his retirement in 1984 from Getty Oil Company as Vice-President and General Manager of the Southern Exploration and Production Division. He was a member of the Geology Foundation Advisory Council at the Jackson School of Geosciences. Cynthia Oualline currently lives in Austin, Texas.

**Getty Oil Company Centennial Chair in Geological Sciences**

**American Association of Petroleum Geology**

# Scientific Scope

The Harrington symposium on the Geology of the Aegean is geared towards appealing to and educating researchers, students, and the general public regarding the importance of the Aegean in understanding Earth history.

Researchers submitted talks under these general themes:

- **The geology of Aegean in general**

Presenters will provide overview talks or presentations regarding the general tectonics of the Aegean. These abstracts focus on outstanding problems and key tectonic features that would appeal towards a broad geologic community.

- **The geologic history of specific domains within the Aegean** (Cyclades, Menderes, Kazdag, Rhodope, Crete, southern Balkans, etc),

Talks are geared more towards specific processes occurring within a single distinct domain within the Aegean. We requested submissions from all fields-- geophysics, geochemistry, tectonics, structural geology, geochronology, petrology, hydrology, sedimentology, etc.

- **The dynamic tectonic processes that occur within the Aegean**

Dynamic processes include, but are not limited to, large-scale plate tectonic extension, strike-slip, or compression movements, orogenic collapse, subduction zone processes, seismic activity, volcanism, polymetamorphism.

- **Its geo-archeological history, natural history and hazards**

Description of links between the geology and archeology of the Aegean region. The timescale for this session differs from those in the other sessions, and are geared towards human affairs.

- **Comparisons of the Aegean to regions elsewhere** (e.g., Basin and Ranges; Asian extensional terranes)

The Basin and Range of western USA and the Aegean contain many common structural elements such as well-developed metamorphic core complexes detachment surfaces, turtleback faults, extensional folds, and supra detachment basins. In addition, the Aegean exposes a wide variety of lithologies, from extensional-related granites, polymetamorphic garnet-bearing assemblages, blueschists, and a wide variety of sedimentary rocks. The session provides an opportunity to translate knowledge across continents.

# Organizing Committee

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# Administrative Arrangements

1. **Registration/Help desk.** Meeting registration will occur during the reception at the Harry Ransom Center, 21st and Guadalupe, 5:30-8:30PM.

   Those who cannot attend the reception at the Harry Ransom Center can pick up meeting materials in JGB 2.326 (just outside of the Boyd Auditorium, JGB 2.324) in the Jackson School of Geosciences.

2. **Accommodations**. The official conference hotel is:

   The Doubletree Hotel Austin. 6505 IH-35 North, Austin, Texas, United States 78752-4346. Tel: 1-512-454-3737; Fax: 1-512-454-6915. http://doubletree1.hilton.com/en_US/dt/hotel/AUSLNDT-Doubletree-Hotel-Austin-Texas/index.do

3. **Name Badges.** Registered participants should display their name badges at all the scientific sessions and social events during the meeting.

4. **Lunches and Snack Breaks**. Box lunches will be provided (Turkey, Roast Beef, or Vegetarian sandwiches, fruit, chips, water) outside of room JGB 2.326. The Turkish Student Association will provide snack breaks during the symposium in room JGB 2.326. Coffee, tea, and soft drinks should be available throughout the days. Please show your name badge to participate in this aspect of the program.

5. **Reimbursements**. For those who have been awarded conference support, please provide any and all receipts to Dr. Elizabeth Catlos. She will provide you with a Payee Information Form to fill out which will be needed to ensure a speedy reimbursement. If you have missed this opportunity during the meeting, send all receipts and contact information to Alice Rentz, Jackson School of Geosciences, The University of Texas at Austin, Geol Science Dept, 1 University Station C1100, Austin, TX 78712-0254, USA.

# Scientific Sessions

1. **Oral Sessions**. Oral sessions are in the Boyd Auditorium (JGB 2.324) located on the campus of the University of Texas at Austin in the Jackson School of Geosciences. The room is equipped with PowerPoint capability. Before the start of the session in which you are giving your talk, speakers should take their electronic presentations on a memory stick to the student representative in the Boyd Auditorium. There will be someone available for assistance from 7:00A on April 29$^{th}$ and April 30$^{th}$.

2. **Chairs of Oral Sessions**. Student conveners will chair the scientific program. Check at the Registration/Help desk for last minute changes in the program.

3. **Speaker Preparation Room.** Space is available for speakers to practice their talk in JGB 2.326. Speakers will need to bring their own computer and power adaptor if needed. Internet can be available if requested. The room will be open from 7:00A-5:00P on April 29$^{th}$ and 30.

4. **Poster Session**. The poster session will be held during the student hosted reception on Tuesday, April 29$^{th}$. Bring your poster to the reception. Posters should be prepared in portrait mode as standard AGU, EGU, or GSA format. Pins and tack board will be provided for hanging and all posters should be put up during evening reception. Authors should attend their posters during the poster session, 8:00P-9:00P on Tuesday, April 29$^{th}$ (refereshments will be served).

5. **Breakout Sessions.** We have included two breakout sessions, which will be held in the Barrow Conference Room on the 4$^{th}$ floor of JGB. This is a smaller room, intended for those interested in actively participating in discussions. Maximum capacity is limited to 40 people. If more are interested, other rooms will be made available. The sessions are:

   **I. What is the future of research in extensional tectonics?** What are the present major research questions in extensional tectonics? What kind of multidisciplinary research can be proposed to solve these questions? Chairs are **Gary Axen (New Mexico Tech) and Michael A. Murphy (Univ of Houston).**

   **II. What is the future for Aegean research?** This session will address the following questions: What are the outstanding research and science questions that future studies of the Aegean can address? How can this symposium facilitate new collaborations and partnerships? Where should future field workshops occur to be of interest to a wide spectrum of participants? What are the pertinent observations and experiments crucial for defining, constraining, and testing models of lithospheric deformation in the Aegean? How does present research help constrain the mechanical, rheological, thermal, and structural development of extensional systems? What are the key questions for each discipline represented in the symposium? What geochemical methods are needed to obtain timing constraints in the Aegean? What is the relationship the extensional tectonics of the Aegean and its natural history and hazards? Chairs are: **Ibrahim Cemen (Oklahoma State Univ), Yildirim Dilek (Miami Univ. Ohio), and John Kappelman (UT Austin).**

# Social Events

1. **Reception at the Harry Ransom Center, Monday April 28th**

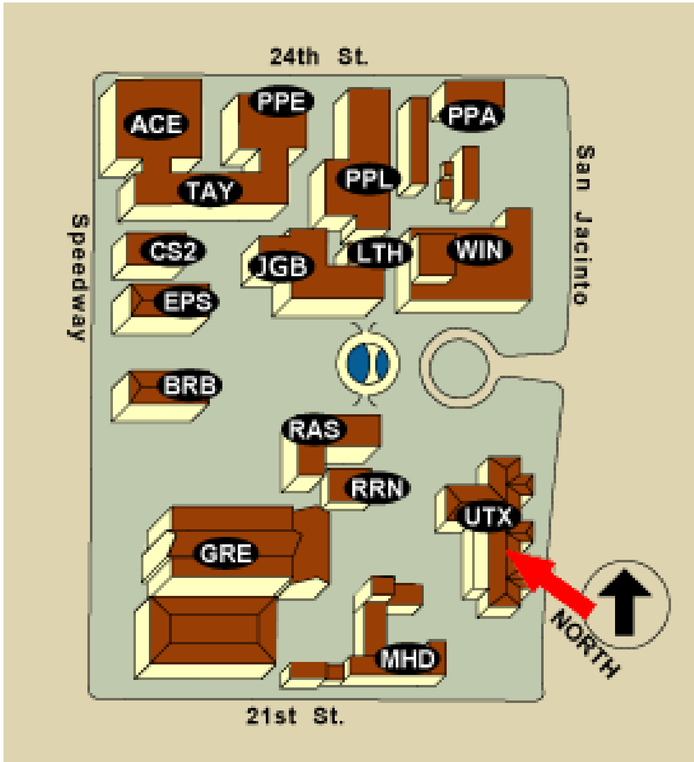
| Time | Description | Location |
|---|---|---|
| 5:30P-8:30P | Reception and registration at the Harry Ransom Center | 21st and Guadalupe Streets<br>Phone: 512-471-8944 |
| 5:30P-6:00P | Registration | Harry Ransom Center |
| 6:00P-6:30P | **B. Clark Burchfiel**<br>The Aegean: A Natural Laboratory for Tectonics | Prothro Theater, Harry Ransom Center |
| 6:30P-7:00P | **George H. Davis**<br>Archaeological Elements of Mt. Lykaion Sanctuary of Zeus (southern Peloponnesos) in Relation to Tectonics and Structural Geology | Prothro Theater, Harry Ransom Center |
| 7:00P-8:30P | Tapas and Wine Bar<br>*On the Road with the Beats Exhibit*<br>Music provided by the Turkish Student Association | Harry Ransom Center |

2. **Evening Reception at the Texas Exes, Tuesday April 29th.** Intended for students, alumni, teacher participants, keynote speakers, and presenters.

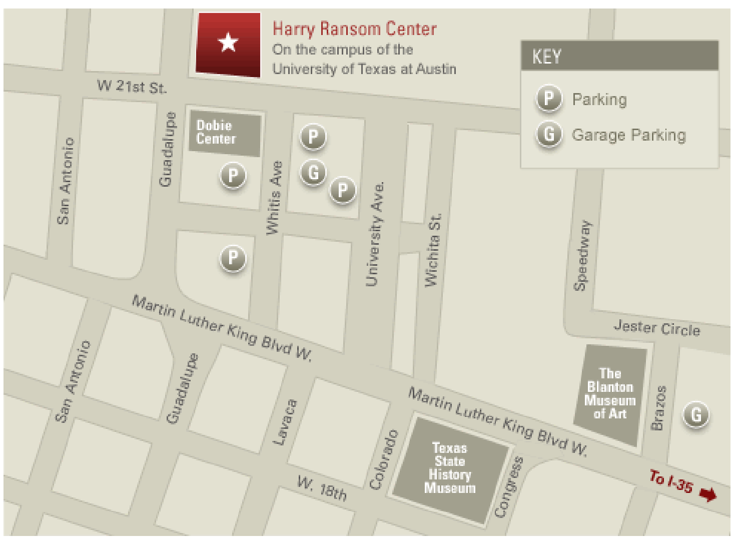
| Time | Description | Location |
|---|---|---|
| 6:45P-10:45P | American Association for Petroleum Geologists Student Chapter will hosted Reception for alumni, students, and presenters | Texas Exes<br>Main Lounge and Concourse<br>2110 San Jacinto<br>Phone: 512-471-0795 |
| 6:45P-7:00P | Arrival to Texas Exes. Welcome, introduction of officers of AAPG and students involved in the symposium. | Host- student Eric Anderson |
| 7:00P-8:00P | Fiesta! Themed Buffet (Beef and Chicken Fajitas, Tostadas, Vegetarian choices) Limited host bar with drink tickets. Cash bar after tickets are redeemed | |
| 8:00P-9:00P | Poster presenters will stand by their posters at this time. | |
| 9:00-10:45P | Evening discussions | |

# Maps

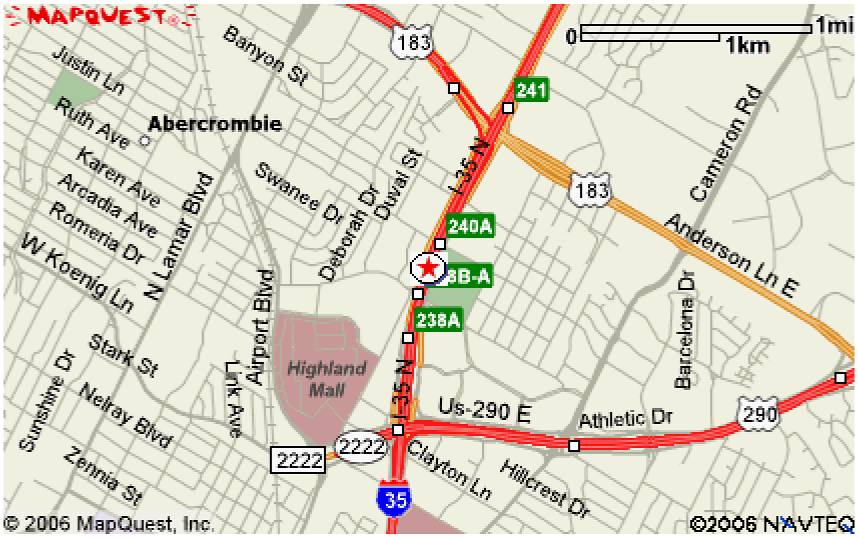
1. **Jackson School of Geosciences**. The building is abbreviated JGB. Please see www.utexas.edu/maps.




2. **Harry Ransom Center**. Please see www.hrc.utexas.edu.



3. **Doubletree Austin Hotel**. Please see: doubletree1.hilton.com/en_US/dt/hotel/AUSLNDT-Doubletree-Hotel-Austin-Texas/index.do



# Program

*Tuesday, April 29, 2008*

8:00-8:05A. Introductory Remarks. **Mark Cloos***
***Getty Oil Company Centennial Chair in Geological Sciences***

CHAIRS: **Mark Cloos and Elizabeth Catlos**

8:05-8:25A. Thrusts and extensional detachments within the Cretan tectonostratigraphy
**Dimitrios Papanikolaou*** and Emmanouel Vassilakis
***Virgil E. and Mildred L. Barnes Distinguished Lecturer***

8:25-8:45A. Interaction between faulting, magma emplacement and volcanism in the central Aegean
**Sotiris Kokkalas** and Attila Aydin

8:45-9:05A. Core complex related extension of the Aegean lithosphere initiated at the Eocene-Oligocene transition
**Marnie Forster** and Gordon Lister

9:05-9:25A. Spatial and temporal relations between post-collisional Cenozoic magmatism and extensional tectonics in the Aegean region
**Yildirim Dilek**, Safak Altunkaynak, and Harald Furnes

9:25-9:45A. Know your Rigid Indenter: An Overview of the Continental Crust and Lithosphere of the Arabian Plate
**Robert J. Stern*** and Peter R. Johnson
***Robert H. Cuyler Distinguished Lecturer***

9:45A-10:05A. The accretionary model for orogenesis and its application to the evolution of the Aegean crust
**Gordon Lister** and Marnie Forster

10:05-10:30A. **BREAK**. Tea and Coffee service.

STUDENT CHAIRS: **Estibalitz Ukar and Benjamin Andrews**

10:30A-10:50A. The Bodrum Magmatic Centre, SW Anatolia; Its Tectonic and Volcanic Significance in the Geology of the Aegean Region
**Yucel Yılmaz**

10:50A-11:10A. Neogene volcanism and extension in Western Anatolian-Aegean area: a new geodynamic model
**Samuele Agostini,** Carlo Doglioni, Fabrizio Innocenti, Piero Manetti, and Sonia Tonarini

11:10A-11:30A. Cenozoic Extensional Tectonics and Exhumation of the Menderes Massif in the Western Anatolia Extended Terrane, Turkey
**Ibrahim Çemen** and Elizabeth J. Catlos

11:30A-11:50A. Geodetic constraints on present-day deformation of the Aegean extensional region, Greece and western Turkey: Implications for active tectonics

**Robert Reilinger**, Simon McClusky, Demitris Paradissis, and Semih Ergintav

11:50-12:10P. Tectonic block rotation, arc curvature and back-arc rifting: insights into these processes in the Mediterranean and western Pacific
**Laura M. Wallace**, Susan Ellis and Paul Mann

12:10P-1:15P. **BREAK**. Boxed lunches provided.

STUDENT CHAIRS: **John Singleton and Jaime Levine**

1:15P-1:35P. Post-collisional deformation of the Anatolides and motion of the Arabian indenter: a paleomagnetic analysis
**J.D.A. Piper**, O.Tatar, H.Gürsoy, F. Koçbulut, B.L. Mesci and A. Heimann

1:35-1:55P. Metamorphic and Ar/Ar geochronology constraints on the Alakeçi shear zone: implications for the extensional exhumation history of the northern Kazdağ Massif, NW Turkey
**Nikolay Bonev**, Laurent Beccaletto, Martin Robyr, Patrick Monié

1:55-2:15P. Monazite Geochronology, Magmatism, and Extensional Dynamics within the Menderes Massif, Western Turkey
**Elizabeth J. Catlos**, Courteney Baker, Sorena S. Sorensen, Ibrahim Çemen, Mete Hançer, Cenk Ozerdem

2:15-2:35P. Consequences of thermal input and fluid flow during metamorphic recrystallization of contact terranes
**Barbara L. Dutrow**, Carl W. Gable and Bryan J. Travis

2:35-2:55P. Nature of Beypazari Granitoid: Geology and Geochemistry, Northwest Anatolia, Turkey
**Yusuf Kagan Kadioglu**

2:55-3:15P. Trace element geochemistry and isotopic composition of mafic and ultramafic cumulate xenoliths in alkaline basalts from the eastern Rhodopes, Bulgaria: Inferences on deep processes under the metamorphic core complexes
**P. Marchev**, S. Arai, Y. Ishida, M. Shirasaka, and H. Downes

3:15P-3:40P. **BREAK**. Tea and Coffee service.

STUDENT CHAIRS: **Josh Garber and Eric Kelly**

3:40-4:00P. Structural and $^{40}Ar/^{39}Ar$ age constraints on the Kulidjik nappe: a record of an early Alpine thrust tectonics in the northeastern Rhodope Massif, Bulgaria
**Nikolay Bonev**, Richard Spikings, Robert Moritz, and Peter Marchev

4:00-4:20P. Metamorphic Style and Development of the Blueschist- to Eclogite-Facies Rocks, Cyclades, Greece
**John C. Schumacher**, John B. Brady, John T. Cheney, Horst R. Marschall, and David Miller

4:20P-4:40P. Diverse P-T paths for the Cycladic ultramafic rock associations: constraints on their origin, emplacement and exhumation
**Yaron Katzir**, Zvi Garfunkel, Dov Avigad and Alan Matthews

4:40-5:00P. Integrated thermochronometric and structural constraints on the exhumation of the western Cycladic metamorphic core complexes
**Daniel F. Stockli**, Bernhard Grasemann, David Schneider, Melissa Wolfe, Michael Edwards, and Kostas Petrakakis

5:00-5:20P. The unroofing history of Naxos and Paros: Constraints and questions from thermochronology and thermal modeling
**Richard A Ketcham** and Stephanie Brichau

5:20-6:30P. **Breakout Session I. Discussion: What is the future of research in extensional tectonics?** What are the present major research questions in extensional tectonics? What kind of multidisciplinary research can be proposed to solve these questions?
Chairs: **Gary Axen and Michael A. Murphy**

6:45-10:45P. Student reception for alumni, students, and contributors to the symposium. Sponsored by the American Association of Petroleum Geologists.

**Poster Session (to be held during the student reception):**

- Deciphering monazite ages in the Menderes Massif in Western Turkey, using cathodoluminescence, electron microprobe and ion microprobe techniques, **Courteney Baker**, Elizabeth J. Catlos, Sorena S. Sorensen, and Ibrahim Cemen
- Geoarchaeological Research of the ilyasbey Mosque and Its Complex Buildings with Ground Penetrating Radar in Miletus, izmir- Western Anatolia Turkey *,* **Selma Kadioglu**, Yusuf Kagan Kadioglu and Ali Akin Akyol
- Native of the marble in Nysa city of Hellenistic and Roman Period, Aydin-Western Anatolia – Turkey*,* Musa Kadioglu and **Yusuf Kagan Kadioglu**
- Paleoseismic investigations along a key active fault within the Gulf of Corinth, Greece, Ioannis Koukouvelas, **Sotiris Kokkalas**, and Paraskevas Xypolias

## *Wednesday, April 30, 2008*

STUDENT CHAIRS: **Benjamin Andrews and Estibalitz Ukar**

8:30-8:50A. The 365 AD earthquake and tsunami: Implications for tectonics and tsunami hazard of the Eastern Mediterranean
**Beth Shaw,** J. A. Jackson, N.N. Ambraseys, G.J. Gorman, C.C. Pain, M. D. Piggott P. C. England, M. A. Floyd, T. F. G. Higham, and J-M. Nocquet

8:50-9:10A. Migrations and adaptations of early *Homo* in western Turkey
**John Kappelman**, Mehmet Cihat Alçiçek, Nizamettin Kazancı, Michael Schultz, Lawrence Todd, and Mehmet Özkul

9:10-9:30A. Constraints on Replenishment, Magma Mixing, and Crystal Recycling Processes at Santorini Volcano, Greece
**Victoria Martin**, Dan Morgan, Dougal Jerram, and Jon Davidson

9:30-9:50A. Orogenic vs anorogenic lamproites in a single volcanic province: lamproites from Turkey
**Dejan Prelevic**

9:50-10:10A. TBA. **Mark Brandon**

10:10-10:30A. Copper isotope geochemistry of volcanogenic massive sulfide deposits of the eastern Pontides, Turkey
**Todd B. Housh** and Emin Çĭftçĭ

10:30-11:00A. **BREAK**. Tea and Coffee service.

***Special Session sponsored by the Fred L. and Frances J. Oliver Lectureship***

STUDENT CHAIRS: **Jaime Levine and John Singleton**

11:00-11:20A. Mechanics of Non-Andersonian Conjugate Strike-Slip Faults in Active Collisional Orogens: Observations, Theories and Implications for Laterally Moving Asthenospheric Flow
**An Yin** and Michael H. Taylor

11:20-11:40A. Geomorphic Response of an Active Metamorphic Core-Complex in a Collisional Orogen: Example from the Lunggar Shan, Southern Tibet
**Michael Taylor**, Paul Kapp, Daniel Stockli

11:40-12:00P Extensional Tectonics in the Basin and Range of Western North America
**Gary J. Axen**

12:00-12:20P. Relationships Between Crustal Structure and Extension in the Basin and Range Province and East Africa
**G. Randy Keller**

12:20P-12:40P. Death Valley turtlebacks: Mesozoic contractional structures overprinted by Cenozoic extension and metamorphism beneath syn-extensional plutons
**Terry L. Pavlis**, Marli Miller′ and Laura Serpa

12:40-2:00P. **BREAK**. Boxed lunches provided.

2:00-3:30P. **Breakout Session II. What is the future for Aegean research?**
What are the outstanding research and science questions that future studies of the Aegean can address? How can this symposium facilitate new collaborations and partnerships? Where should future field workshops occur to be of interest to a wide spectrum of participants? What are the pertinent observations and experiments crucial for defining, constraining, and testing models of lithospheric deformation in the Aegean? How does present research help constrain the mechanical, rheological, thermal, and structural development of extensional systems? What are the key questions for each discipline represented in the symposium? What geochemical methods are needed to obtain timing constraints in the Aegean? What is the relationship the extensional tectonics of the Aegean and its natural history and hazards?
Chairs: **Ibrahim Cemen, Yildirim Dilek, John Kappelman**

Coffee and tea will be provided during this breakout session.

3:30-5:00P. Continue discussions over refreshments elsewhere in Austin.

# Symposium Abstracts

## Neogene volcanism and extension in Western Anatolian-Aegean area: a new geodynamic model

**Samuele Agostini[1]*, Carlo Doglioni[2], Fabrizio Innocenti[3], Piero Manetti[4], and Sonia Tonarini[1]**
[1]Istituto di Geoscienze e Georisorse, CNR –Pisa, ITALY
[2]Dipartimento di Scienze della Terra, Università La Sapienza, Roma, ITALY
[3]Dipartimento di Scienze della Terra, Università di Pisa, and IGG – CNR, Pisa, ITALY
[4]Dipartimento di Scienze della Terra, Università di Firenze, and IGG – CNR, Pisa, ITALY
(*corresponding author = s.agostini@igg.cnr.it)

The widespread Western Anatolian-Aegean Neogene volcanism presents a complex geochemical evolution reflecting the uncommon space-time variability of the geodynamic setting of the region.

The main items to be considered are:

i) In Western Anatolian and Central Aegean, the older activity is widespread typical "supra-subduction" magmatism, with calc-alkaline to shoshonitic affinity.
ii) This phase of activity ends by spots of ultra-potassic lavas and dykes, sometimes with lamproitic characters.
iii) From Late Miocene onwards scattered alkali basaltic lavas with intraplate affinity were emitted, while calc-alkaline activity settled on South Aegean region.

Since Late Oligocene-Early Miocene the region was, and still is, affected by extensional tectonics generally ascribed to a backarc rift.

However the Aegean region should rather be considered as an unconventional backarc since its characters and geodynamic constraints rather differ from "typical" backarc settings. In fact, in spite of a long lasting (>40Ma) active NE-directed subduction of Africa, the backarc area still maintains a relatively thick continental crust (>20-25 km), unlike the fast oceanization of typical backarc basins associated to W-directed subduction zones. Moreover, the upper Eurasian plate is overriding the lower Africa plate with separate segments, i.e., Greece faster, and Turkey slower. The differential velocity between Greece and Turkey determines extension in the upper plate, unrelated to the loss of subducted retreating lithosphere, which is the usual setting for the origin of "classic" backarc settings.

The geodynamic framework is supported by the geochemical and isotope features of the supra-subduction magmas revealing the occurrence of a trapped, drying slab, with progressive decreasing of Fluid Mobile Elements/Fluid Immobile Elements ratios, $\delta^{11}B$ and $\delta^{7}Li$, coupled with scarce variations of Sr and Nd isotopes.

Moreover, the differential motion between the Greek and Anatolian micro-plates creates tear zones with the formation of slab ruptures or vertical slab windows. The occurrence of such windows is, in fact, outlined by the presence of alkali basalts with intraplate affinity sourced in the sub-slab mantle (low $^{87}Sr/^{86}Sr$, high $^{143}Nd/^{144}Nd$, high FME/FIE ratios, typical mantle values of $\delta^{11}B$ and $\delta^{7}Li$).

## Extensional Tectonics in the Basin and Range of Western North America

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After late Proterozoic rifting and Paleozoic passive-margin development, western North America experienced subduction, accretion, retroarc thrusting, and lateral terrain translations.

Widespread extension began with metamorphic core complex (MCC) formation in a Paleocene back- or intra-arc setting in the NW US and SW Canada. MCC extension rapidly spread south to E Nevada and W Utah, probably triggered by collapse of the low-angle Laramide slab and attendant heating of the base of North American lithosphere. In late Oligocene-early Miocene time, extension occurred in E Mexico, W Texas and the Rio Grande Rift. Extension in Mexico spread west along with west-migrating arc volcanism, but "jumped" across the unextended Sierra Madre Occidental batholith. MCC extension in the southern Basin and Range (Arizona, New Mexico, and Sonora, Mexico) began at this time and propagated NW, to SE California, probably in response to a combination of slab rollback and a N-migrating slab window. Extension at ~18-16 Ma in S Nevada linked the N and S basin and range, and extended crust surrounded the strong Colorado Plateau on the W, S and E. Subsequent extension in Arizona and the Rio Grande Rift was relatively minor but rapid extension in Nevada and E California continued on steeply to gently dipping faults, forming half-graben basins with tilted footwall ranges and local MCCs. WNW- and ESE-striking dextral and sinistral faults, respectively, formed in conjunction. During late middle to late Miocene time, subduction ceased, volcanism switched from calcalkaline to bi-modal alkaline, the dextral San Andreas fault system evolved, the extension direction rotated CW, and the dextral-oblique extension began in the Gulf of California and Walker Lane-eastern California shear zone. Lithospheric rupture in W North America occurred in latest Miocene-Pliocene time during rapid oblique dextral extension in the Gulf of California, probably in response to basal traction along the continental margin and increased strain rates between the strong Sierra Madre and Peninsular Ranges batholiths. This left significant lateral variation in Moho depth and degree of continental extension prior to lithospheric rupture, and created normal ocean crust in the S gulf, but thick (~20 km) juvenile mafic + metamorphic + sedimentary crust in the N gulf.

## Deciphering monazite ages in the Menderes Massif in Western Turkey, using cathodoluminescence, electron microprobe and ion microprobe techniques

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The Menderes Massif is a large metamorphic core complex that exposes over 40,000 $km^2$ of metamorphic and igneous rocks via large-scale extension. This massif is a key Aegean feature and understanding the mechanisms behind the extension is important to understanding the history of the tectonics of the Aegean. Granites cut by the Alasehir detachment surface, which bounds the northern edge of the core complex, contain monazite grains than range from Late to Early Miocene. The grains were dated in thin section using an ion microprobe (Th-Pb). The ion microprobe is used because this method enables us to keep the grains in question intact and preserves the rock. To understand the reason for the ~10 m.y. discrepancy, we applied backscattered and secondary electron imaging, cathodoluminescence (CL), and X-ray element mapping. Cathodoluminescence is used to show zonation in the feldspars, and plagioclase and features in the quartz such as micro-fractures that cannot be seen with the electron microprobe. Monazite does not luminesce. However surrounding minerals show CL evidence of fluid flow that indicate the possibility of dissolution/reprecipitation reactions. The CL images show the granites contain plagioclase with corroded cores and distinct rims, and quartz in some samples show evidence for brecciation and subsequent recrystallization. The CL shows that the feldspars are zoned from core to rim, and are different in color along twin planes. Radiation haloes can also be detected around many of the monazite grains. The dated monazite grains are chemically zoned, which is seen by element mapping of Th, Ce, Y and U. However, the mineral's composition does not always represent a different age. The granites visibly range in degree of alteration, depending on their proximity to the Alasehir detachment. Whole and trace element rock chemistry from the granites show they experienced a complicated magmatic history, consistent with the CL images. The combination of electron microprobe, ion microprobe and CL techniques are useful for deciphering the complicated history of the granites exposed along the Alasehir detachment, and can be applied to elsewhere to regions that have experienced a polyphase magmatic and tectonic history.

## Metamorphic and Ar/Ar geochronology constraints on the Alakeçi shear zone: implications for the extensional exhumation history of the northern Kazdağ Massif, NW Turkey

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The Kazdağ Massif exposes a metamorphic dome in the Biga Peninsula of northwest Turkey. An extensional origin has been proposed for the dome, limited on both flanks by detachments and/or shear zones. The northern flank is bounded by the extensional Alakeçi Shear Zone (ASZ), whose P-T-t path is still poorly known. We therefore focus on its metamorphic conditions and related temporal history to precise its tectono-metamorphic evolution. The local tectonostratigraphy in structurally ascending order comprises: (i) the high-grade metamorphic core rocks of the Kazdağ Massif (gneisses and micaschists intercalated with amphibolites and marbles); (ii) the two kilometer-thick ASZ; (iii) the overlaying unmetamorphosed pre-Cenomanian accretionary Çetmi mélange; and (iv) Neogene sedimentary and volcanic cover rocks.

ASZ mylonites were derived from both the core rocks and the mélange lithologies. From the north to the south the mylonitic fabrics in the ASZ depict a top-to-the N-NNE shearing, parallel to the NNE-plunging stretching lineation and NNW-dipping mylonitic foliation. This geometry implies normal sense movement i.e. north-side down-dip extensional displacement along this flank of the Kazdağ Massif. The northward transition from ductile to brittle-ductile regime through the ASZ shows that the deformation occurred at decreasing temperatures and degree of metamorphism. The paragenesis in equilibrium within the mylonitic gneisses and schists contains Qtz + Fs + Ms + Bt + Grt ± St ± Sill, with late retrogressive chlorite after biotite and garnet. Four samples of ASZ rocks yielded pressures between 6.9-5.7 kbar and temperatures between 706-587 °C. Three samples from the mylonitic rocks supplied in situ isochron $^{36}Ar/^{40}Ar$ mica ages between 31.2-24.2 Ma, which we interpret to date the cooling of the mylonites following the P-T decrease across the ASZ. The metamorphic and structural results support the extensional character of the ASZ, and sketch transition from sillimanite core gneisses in the deeper structural levels to chlorite schists towards the top of the shear zone.

These new data allow to precise the peak P-T conditions and the temporal evolution in the northern flank of the Kazdağ Massif, where Late Oligocene extensional exhumation was assisted by NNE-directed ductile-brittle ASZ, which had operated from amphibolite to greenschist facies. At the regional scale, this tectono-metamorphic pattern is similar to those observed on other places of the north Aegean domain.

## Structural and $^{40}Ar/^{39}Ar$ age constraints on the Kulidjik nappe: a record of an early Alpine thrust tectonics in the northeastern Rhodope Massif, Bulgaria

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In the northeastern Rhodope Massif, a unique juxtaposition of assumed high-grade basement allochthon onto a low-grade Mesozoic unit is exposed in the Kulidjik nappe. The thrusting is interpreted as post-Jurassic to pre-Late Eocene. The tectonostratigraphy comprises the following units: (i) an upper unit of high-grade basement of the eastern Rhodope consisting of various amphibolite facies rocks with metaophiolite lenses; (ii) an overlaying Mesozoic (including Jurassic radiolarians) low-grade unit; (iii) a structurally overlaying allochthon of the Kulidjik nappe; and (iv) unconformable Late Eocene sedimentary and Oligocene volcanic cover rocks.

The basement unit contains a NNE-SSW oriented lineation rarely associated with top-to-the NNE ductile shearing. Greenschist facies retrogression of this unit is diagnostic of local thrusting of the overlying low-grade unit. The greenschists of the low-grade unit represent arc metavolcanic rocks overlain by phyllites. The structural elements in this unit have similar attitudes as the basement unit. Kinematic indicators in the low-grade unit demonstrate internal top-to-the NNE ductile shearing during greenschist facies conditions. The allochthon consists of klippen composed of muscovite-albite gneisses. The flat-lying thrust contact with ductile-brittle deformation contains mylonites and cataclasites. Previously reported local top-to-the SSW ductile shearing in the allochthon is probably a consequence of shear instabilities. Deformation-crystallization relationships revealed fabrics in the allochthon compatible with greenschist up to lower amphibolite facies conditions without retrogression and similar ENE-verging fold patterns in the low-grade unit and the allochthon at the thrust contact. Two muscovite samples from distinct klippen yielded inverse isochron $^{40}Ar/^{39}Ar$ ages of 156.07±1.30 Ma and 162.62±2.69 Ma, which reflect cooling below 350°C of the allochthon associated with its exhumation during emplacement after greenschist-lower amphibolite facies metamorphism.

Structural data indicate NNE-directed tectonic transport of the low-grade footwall unit, which is consistent with emplacement in comparable metamorphic conditions, and the thrust direction of the allochthon in the hanging wall. The subduction-accretionary origin of the low-grade unit and the new age results allow us to link this tectono-metamorphic event to Late Jurassic thrust imbrication of arc units on the Rhodope basement, which is the first time that early Alpine thrust tectonics in the northeastern Rhodope Massif have been recognized.

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## Potassium metasomatism, mineralization, and reset ages at detachment faults in the southwestern United States

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Potassium metasomatized Tertiary lavas with anomalously high $K_2O$ (~2-13 wt%) and low $Na_2O$ (~0.1 wt%) content are distributed within the northwest-trending Miocene extensional terrane of the southwestern United States. These highly-altered rocks are common in the upper-plate of several core-complex-related detachment faults. Intensity of the metasomatism is spatially related to distance from the surface expression of the detachment. Specific examples include Picacho Peak and the Harcuvar Mountains in Arizona and the Grant Range in Nevada. In addition to systematic changes in $K_2O$ and $Na_2O$ content, the rocks may also be enriched in Zr and depleted in MgO.

Manganese, barite, copper oxides, minor gold, and other metals may also be present at the detachment or in the upper-plate. Adularia, quartz, and calcite have also been introduced. The upper-plate rocks commonly have a brick-red color; however, the biotite appears fresh.

K-Ar whole-rock and biotite ages; zircon and apatite fission-track ages; and $^{40}Ar/^{39}Ar$ ages on biotite and adularized sanidine are discordant. Regionally, eruption ages appear to be ~25-31 Ma;

however, alteration and mineralization are younger events that took place in response to fluids that moved along the detachment pathway ~17-22 Ma at temperatures that did not exceed 280°C. The specific mechanism for extension and the source of the fluids is unknown.

## The Aegean: A Natural Laboratory for Tectonics

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The Aegean, a young and active tectonic region, is a natural laboratory for analyzing many tectonic processes that occur in backarc extensional regimes, and the correlation of these processes from landscape development to deeper mantle dynamics. Cenozoic development of the Aegean region was dominated by subduction beneath Europe and coeval upper plate extension modified by westward extrusion of Anatolia. Intraorogenic and backarc extension began during early Cenozoic time within the Balkans and NW Turkey during closure of the Vardar ocean. Extension was manifested by core complex formation and a change in volcanism caused by the evolution of the lithosphere and mantle wedge. Following a short period of local (?) shortening in ~ early Miocene time, regional extension began and continued to the present. Within the Hellenides, E-W extension and the subduction zone migrated westward as thick and thin crustal units were progressively accreted and were complexly rotated up to 40° CW. Within the eastern Balkans and NW Turkey, N-S extension migrated westward and southward, and in the Aegean the volcanic arc and subduction zone migrated southward. Turkish crustal elements rotated complexly CCW, which in concert with the CW rotation in the Hellenides increased the curvature of the subduction zone and lengthened the orogen causing greater subsidence and extension in the Aegean Sea. Westward extrusion of Anatolia from the Arabian collision zone was enhanced by slab roll back in west moving Aegean crust more rapidly westward. Abundant evidence supports slab rollback at different velocities along the subduction zone. In Pliocene time, the North Anatolian fault crossed the Hellenides in a complex transtensional zone and a diffuse zone of left-lateral shear crossed western Turkey at present isolating a relatively undeforming Aegean plate.

Major tectonic questions include: What is the geometry and fate of subducted slabs ?, How much crust is accreted during subduction of thick and thin crust?, Does crustal accretion cause slab break off or only changes in slab dip ?, How does the mantle wedge evolve and how is this expressed in the volcanism ?, How much lateral mantle flow occurs during changes in slab geometry and rotation of crustal elements ?, and What is the relation of mantle and crustal structure to first order landscape development?

## Monazite Geochronology, Magmatism, and Extensional Dynamics within the Menderes Massif, Western Turkey

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The Menderes Massif (western Turkey) is an important metamorphic core complex located in the Aegean region; geochemical and geochronological data from this extensional domain facilitates our understanding of large-scale extension of the Earth's lithosphere. S-type, peraluminous granites (Salihli and Turgutlu) that intrude the detachment that bounds the northern edge of the central Menderes Massif may have been generated due to subduction of the Eastern Mediterranean floor along the Hellenic trench. In situ Th-Pb ion microprobe monazite ages from the granites range from 21.7±4.5 Ma to 9.6±1.6 Ma (±1$\sigma$), which could record their exhumation history. Higher uncertainty in the ages is attributed to monazite common Pb and the range is due to fluid-mediated dissolution-reprecipitation reactions. Cathodoluminescence images of the granites document the presence of fluids and multiple episodes of mineral growth and retrogression. The oldest ages from the granites overlap with Early Miocene inclusions in garnet and matrix monazites from surrounding metamorphic assemblages (Bozdag and Bayindir nappe). Pressure-temperature (P-T) conditions, garnet zoning, and monazite ages from the nappe samples show that these rocks experienced disparate metamorphic events and are in disequilibrium. One Bozdag sample contains both prograde garnets and those affected significantly by diffusion, and yields monazite ages from 31.5±2.7 Ma to 22.8±2.4 Ma (±1$\sigma$). Ages reported here are similar to dates constraining extension reported elsewhere in the Aegean, but indicate a level of complexity when linking movement within the Menderes Massif to large-scale geodynamic processes that created other metamorphic core complexes in the region.

## Cenozoic Extensional Tectonics and Exhumation of the Menderes Massif in the Western Anatolia Extended Terrane, Turkey

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The Western Anatolia Extended Terrane in Turkey is located on the eastern side of the Aegean Extended Terrane and contains one of the largest metamorphic core complexes in the world, the Menderes massif. It has experienced a series of continental collisions from the Late Cretaceous to the Eocene during the formation of the Izmir-Ankara-Erzincan suture zone. Based our field work and monazite ages, we suggest that the north-directed postcollisional Cenozoic extension in the region is the product of three consecutive stages, triggered by three different mechanisms.

The first stage was initiated about 30 Ma ago, in the Oligocene by the Orogenic Collapse the thermally weakened continental crust along the north-dipping Southwest Anatolian shear zone. The shear zone was formed as an extensional simple-shear zone with listric geometry at depth and exhibits predominantly normal-slip along its southwestern end. But, it becomes a high-angle oblique-slip shear zone along its northeastern termination. Evidence for the presence of the shear zone includes (1) the dominant top to the north-northeast shear sense indicators throughout the Menderes massif, such as stretching lineations trending N10E to N30E; and (2) a series of Oligocene extensional basins located adjacent to the shear zone that contain only carbonate and ophiolitic rock fragments, but no high grade metamorphic rock fragments. During this stage, erosion and extensional unroofing brought high-grade metamorphic rocks of the Central Menderes massif to the surface by the early Miocene.

The second stage of the extension was triggered by subduction roll-back and associated back-arc extension in the early Miocene and produced the north-dipping Alaşehir and the south-dipping Büyük Menderes detachments of the central Menderes massif and the north-dipping Simav detachment of the northern Menderes massif. The detachments control the Miocene sedimentation in the Alaşehir, Büyük Menderes, and Simav grabens, containing high-grade metamorphic rock fragments.

The third stage of the extension was triggered by the lateral extrusion (tectonic escape) of the Anatolian plate when the North Anatolian fault was initiated at about 5 Ma. This extensional phase produced the high-angle faults in the Alaşehir, Büyük Menderes and Simav grabens and the high-angle faults controlling the Küçük Menderes graben.

## Archaeological Elements of Mt. Lykaion Sanctuary of Zeus (southern Peloponnesos) in Relation to Tectonics and Structural Geology

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The Sanctuary of Zeus is the focus of the Mt. Lykaion Excavation/Survey (University of Pennsylvania, University of Arizona, and 39th Ephorate of Prehistoric and Classical Antiquities). It was described by Pausanias as a sacred place of pan-Hellenic significance, with stadium and hippodrome in which athletic games were held, a sanctuary of Pan, and a formidable temenos and altar of Lykaion Zeus. In picturing human activity on this mountain during ancient times, it is not adequate to treat the mountain as if it were simply a tall, symmetrical, and handy edifice within which rock contents are irrelevant, for the geology *within* Mt. Lykaion significantly influenced what was built *on* it, and where! There are contemporary reminders of the 'power' of the site, including the devastating April, 1965, Megalopolis earthquake, the epicenter of which was merely 4 km away. In fact, there are active normal faults within the Sanctuary. However the primary geoarchitecture is that of the Pindos fold and thrust belt, fashioned largely in Cretaceous through Eocene. Mt. Lykaion's dome-like summit is a thrust klippe separated from underlying nappes by a major thrust fault (Lykaion thrust), the subhorizontal trace of which encircles the mountain creating a subtle bench in the landscape coinciding closely with archaeological and natural elements important to the Sanctuary (e.g., stoa, seatwall, fountains, trails). Late Jurassic through Eocene "Pindos Group" formations are stacked and repeated by the thrusting. Inter-relationships between bedrock, structure, and archaeology are revealed in a "geoarchaeological column," which displays positioning of elements in relation to the thrust, and orientations of rock formations in relation to flat patches in otherwise steep, rocky country, which became sites suitable for placement of hippodrome, baths, temenos, horse pasturing areas, etc. Worked limestone blocks are locally derived and can be matched with formations. The compelling high elevation of the ash altar is testimony to residual crustal buoyancy achieved through "Pindos" crustal shortening, and the steep processional ascent to the altar speaks to regional active normal faulting and rapid erosion.

## Spatial and temporal relations between post-collisional Cenozoic magmatism and extensional tectonics in the Aegean region

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Post-collisional magmatism in W. Anatolia began in the Eocene & has occurred in discrete pulses throughout the Cenozoic as it propagated from N to S, producing igneous assemblages with varying chemical compositions. This apparent SW migration of magmatism & accompanying extension through time was a result of the thermally induced collapse of the W. Anatolian orogenic belt, which formed during the collision of the Sakarya & Tauride-Anatolide blocks in the E. Eocene. The thermal input & melt sources for this prolonged magmatism were provided first by slab breakoff-generated asthenospheric flow (AF), then by lithospheric delamination-related AF, followed by tectonic extension-driven upward AF. Collision-induced lithospheric slab breakoff provided an influx of asthenospheric heat & melts that resulted in partial melting of the previously subduction-metasomatized mantle lithosphere beneath the suture zone, producing the Eocene & Oligo-Miocene igneous suites. The following magmatic phase during the M. Miocene (16-14 Ma) developed mildly alkaline bimodal volcanic rocks that show a decreasing amount of crustal contamination & subduction influence in time. Both melting of a subduction-modified lithospheric mantle & asthenospheric mantle-derived melt contribution played a significant role during this phase, which was attended by region-wide extension that led to the formation of metamorphic core complexes & graben systems. The last major phase of magmatism in the region, starting ~12 Ma, is represented by L. Miocene to Quaternary alkaline to super-alkaline volcanic rocks that show

OIB-like geochemical features. These rocks are spatially associated with major extensional fault systems that acted as natural conduits for the transport of uncontaminated alkaline magmas to the surface. The melt source for this magmatic phase carried no subduction component & was produced by the decompressional melting of asthenospheric mantle, which flowed in beneath the attenuated continental lithosphere in the Aegean region. This time-progressive evolution of Cenozoic magmatism & extension in W. Anatolia has been strongly controlled by the interplay between regional plate tectonic events & the mantle dynamics, and provides a realistic template for post-collisional magmatism & crustal extension in many orogenic belts.

## Consequences of thermal input and fluid flow during metamorphic recrystallization of contact terranes

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Dynamic recrystallization during metamorphism is a complex feedback among thermal, chemical and mechanical energies. Thermal energy input is dependent on the heat transport mechanism that, in turn, depends on the permeability of the host rocks and the availability of fluids. Fluids alter the rate of heating and the residence time of rocks at elevated temperature (T). Infiltration of fluids from one chemical domain to another may drive reactions that alter the initial permeability field and change the state of stress in the host rocks. The outcome of these interdependent processes is a rock texture that reflects not only the initial bulk composition but also the controlling reaction mechanisms.

Computational experiments of heat and mass transport from tabular intrusions elucidate the impact of fluids on the thermal field experienced by the host rocks during recrystallization. In the near field, purely conductive heat transport from a granitoid intrusion results in a short lived, rapid heating pulse that quickly dissipates, followed by a long cooling cycle. In contrast, advective heat transport results in early heating followed by a longer-lived heating event. The initial conductive pulse is of the same duration and magnitude for each case (for identical starting conditions), but as fluid circulation commences, advection of warm fluids results in an order of magnitude longer-lived heating cycle. The initial thermal pulse provides thermal energy for driving mineral nucleation whereas the later heating cycle provides the driving force for mineral growth. Depending on the time interval between these heating events, mineral textures may appear to be polymetamorphic. These computational studies provide insights into the dynamic processes of heat transport, T, fluid-rock interactions and mineral textures during metamorphism.

## Core complex related extension of the Aegean lithosphere initiated at the Eocene-Oligocene transition

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The South Cyclades Shear Zone (SCSZ) is a ~1 km thick bowed-up ductile shear zone that defines the carapace of a deeply eroded gneiss dome that outcrops on the island of Ios in the Cycladic archipelago, Aegean Sea, Greece. The SCSZ is a key structural element in the tectonic evolution of the Cycladic massif, juxtaposing the Cycladic Eclogite Blueschist Unit (EBU) above, against a Hercynian magmatic and metamorphic basement complex, below. The discovery of the SCSZ played a pivotal role in the recognition of the Aegean metamorphic core complexes, and this supposedly Miocene shear zone has been studied in detail by several authors. We returned to the SCSZ to further the science of argon geospeedometry, and to test the shear heating hypothesis, since earlier work led to the conclusion that short thermal pulses had been associated with the operation of this extensional ductile shear zone.

Here we report new microstructurally focussed $^{40}Ar/^{39}Ar$ geochronology that suggests the SCSZ initiated just before the time of the Eocene-Oligocene transition (at ~35 Ma). Therefore it is not only Miocene extension that led to the Tethyan metamorphic core complexes exposed in the Cycladic archipelago. It is shown here that pervasive top-to-the-south directed ductile shear took place in the SCSZ for ~5 Ma during the early Oligocene, followed by initiation of overprinting north-sense shear zones at the time of the Oligocene-Miocene transition (at ~25 Ma). This means that modern (core complex related) extension in the Aegean started much earlier than has been previously recognized, and that stretching of the Aegean lithosphere took place in a distinctly episodic fashion, not in a manner that can be described as continuous, or progressive. The data also mean that the complementary shear-sense geometry of the SCSZ and the North Cyclades Shear Zone (NCSZ) cannot be interpreted as crustal-scale boudinage initiated during crustal extension in Miocene time, since the opposing sense shear zones operated at distinctly different times. Similarly, models that suppose exhumation of the Cycladic Eclogite-Blueschist Unit as the result of extrusion can also be eliminated.

This research illustrates the difficulties involved in systematically determining the age of deformation fabrics using $^{40}Ar/^{39}Ar$ geochronology, and provides a case study that shows the value of carefully designed step-heating experiments on microstructurally controlled samples. In samples such as these, from complex metamorphic tectonites, laser fusion, or step heating experiments with relatively few steps, would have led to erroneous conclusions.

## Copper isotope geochemistry of volcanogenic massive sulfide deposits of the eastern Pontides, Turkey

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A large number of "Kuroko-type" volcanogenic massive sulfide (VMS) deposits are associated with Jurassic and Late Cretaceous to Eocene arc-like volcanic rocks in the eastern Pontides of NE Turkey. Previous S and O isotope studies indicate that S in the ore minerals was likely derived from basement rocks, while the O isotope data for quartz gangue could indicate either derivation from magmatic water or by quartz-seawater fractionation at about 300°C. Cu isotope studies were undertaken to constrain the source of the copper and to compare with other volcanogenic massive sulfide deposits and black smokers.

Cu isotope data are reported for fifteen deposits. Cu isotopes were measured on chalcopyrite and bornite on the IsoProbe, a multicollector, magnetic-sector ICPMS at The University of Texas at Austin. The data are reported as •$^{65}$Cu relative to the standard AE467 and have a precision of 0.07‰. Chalcopyrite from these deposits have •$^{65}$Cu between +0.45 and -0.62‰, with a mean value of -0.03‰. Four chalcopyrite-bornite pairs were measured. Three of these pairs have the expected relationship with chalcopyrite heavier than bornite; the mean •$_{(cp-bo)}$ for these three pair is 0.40‰. Chalcopyrite from Ergani, a "Cyprus-type" VMS deposit from the Taurides of southeastern Turkey was also measured for comparison. •$^{65}$Cu for the chalcopyrite from this deposit is -0.14, near the mean for the chalcopyrite from the "Kuroko-type" VMS deposits of the eastern Pontides.

The range of values of •$^{65}$Cu for chalcopyrite from studied VMS deposits in the eastern Pontides is 1.07‰. This range is larger than that observed for chalcopyrite from Alexandrinka, a "Kuroko-type," VMS deposit, in the southern Urals (0.63‰), but is significantly smaller than the up to 3‰ variations seen in individual modern sea-floor hydrothermal fields on the Mid-Atlantic Ridge. In all of these deposits, the shift towards lighter •$^{65}$Cu is interpreted to result from oxidation and leaching of previously deposited copper and its redeposition elsewhere in the hydrothermal system. On the basis of the positive •$^{65}$Cu values seen in some of the VMS deposits of the eastern Pontides, it is improbable that the primary copper mineralization in these deposits was derived by leaching and redeposition of copper derived from the underlying basement, but rather suggests a magmatic origin.

## Nature of Beypazari Granitoid: Geology and Geochemistry, Northwest Anatolia, Turkey

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Beypazari granitoid represents one of the widest exposure bodies within the Sakarya continent. They have several exposure bodies at Beypazari, Oymaagac, Tahir, Kirbasi and Yalnizcam of Eskisehir city. Although Beypazari Granitoid has several independence outcrops in the field geology the aeromagnetic anomaly reveal that they are a unique body at the lower part of the crust. Field observation and the mineralogical and petrographical investigation reveal that Beypazari Granitoid is composed of five different units these are monzonite, quartz monzonite, granodiorite, granite and alkali feldspar granite. Alkali feldspar granite cuts all the other subunits in form of aplitic dyke. All the other subunits have gradual contact with the each other. Excluding alkali feldspar granite mafic enclaves are observed within the other 4 subunits as angular and elliptical in shape and changing from mm up to approximately 20 cm in size. These enclaves can be divided genetically into three different types according to the field observation, textural features and mineralogical compositions. The first type has igneous texture, sharp contact with host rock, rimmed by fine crystalline mafic minerals and represents the abundant enclave type within the monzonite, quartz monzonite, granodiorite and granite as elliptical to sub-angular in shape. These enclaves mostly have subophitic texture in the composition of diorite, quartz diorite and monzodiorite. Ocellar quartz, acicular apatite, poiclitic feldspars and blade shaped biotite are the most characteristic features of the first type of these enclaves, which may represent the magma mixing/mingling enclaves in origin. The second type of these enclaves has a cumulate texture and is representing a segregation of early crystallization processes of mafic minerals. The second type of these enclaves is the product of the early crystallization of magmatic differentiation and is forming the magma segregation enclave types. The third type of the enclaves have metamorphic texture with clear metamorphic lineation, sharp contact with host rock and mostly observed at the northwest part of Kirbaşi and Tahir region. They have angular to sub-angular in shape. These types of the enclaves have hornfels in composition at the contact with the host rock as a product of contact metamorphism and amphibolites in composition at the core as a product of high temperature and middle pressure metamorphism. The textural features and mineral composition of the third type of the enclaves may indicate a fragment of metapelitic rocks, which caught by the granitoid magma in the form of xenolithic enclaves.

Whole rock geochemistry reveals that Beypazari granitoids are subalkaline and calcalkaline in nature. They are enriched in Light-REE and LIL with respect to High-REE and HFS elements. Tectonic discrimination diagrams of Beypazari granitoid suggest a product of plate convergence and probably belong to Volcanic Arc Granitoid (VAG). The field observations, mineralogy, petrography with the whole geochemical data reveal that the Beypazari Granitoid magmas are derived from a subduction-modified and metasomatized mantle source with considerable crustal contribution.

## Native of the marble in Nysa city of Hellenistic and Roman Period, Aydin- Western Anatolia - Turkey

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Nysa, one of the most important cities of Caria in Hellenistic and Roman period, is located on the highway connecting Aydin (ancient name Tralleis) and Denizli, at about three kilometres northwest of Sultanhisar in western Anatolia of Turkey. The archeological remains of Nysa are located on the slopes on the side of the stream called Tekkecik. The buildings, streets and public squares of the ancient city were supported by vaulted substructures adapted to the topographic conditions. As to the foundation of the city, Strabo relates that three brothers named Athymbros, Athymbrados, and Hydrelos came from Lakedaimon to Caria, and founded there three cities named after themselves.

The unification of these three cities into Nysa was accomplished in the first half of the third century BC by the Seleucids, presumably by Antiochos I Soter, son of Seleucos. The name Nysa is thought to come from a member of Seleukos family. Nysa prospered greatly during the period of Roman dominance in Anatolia, both materially and culturally. Nysa is one of the most important cities of Roman Asia Minor because of the density of its buildings and because remains of different cultural periods are preserved. Strabo, the famous Roman geographer (63 BC – AD 21), was educated in Nysa.

Present research has so far brought no evidence of the existence of the city before the third century BC. Extant architectural remains and inscriptions as well as small finds prove that the city was inhabited uninterruptedly from Hellenistic to Byzantine times. The known parts of the city today include several public buildings: a theatre, a stadium, an agora, a gerontikon/bouleuterion, a gymnasium, a library, an in antis temple, a bath complex as well as a necropolis. The remains of the Hellenistic city walls have disappeared through time.

The first excavations in Nysa were done by the German railroad engineer Walter von Diest between 1907 and 1909. After this initial research, further excavation was directed by the Greek archaeologist K. Kourounitios in the 1920s. Since 1990, an interdisciplinary team under the direction of Prof. Dr. Vedat İdil from Ankara University has been studying the ancient city. The small rock samples from the building of theatre, stadium, basement of agora and tomb were collected and determined under polarized microscope and confocal Raman spectroscopy to find out the native of these rock sources. The results of these studies reveal that the main rocks of these structures are composed from white colour marble. These marbles have granoblastic texture and are composed of mainly pressure twinned calcite as coarse grain size. The Confocal raman specroscopical studies of reveal that the marble building stone of Nysa city are mainly obtained from Jurassic Cretaceous of Western Anatolia marble.

## Geoarchaeological Research of the ilyasbey Mosque and Its Complex Buildings with Ground Penetrating Radar in Miletus, izmir- Western Anatolia Turkey

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Miletus or Milet, whose old name was Miletus, which were one of the most important city of ancient Iona, are today of great value from cultural standpoint of Turkey. Miletus, situated near the village of Balatin the present district of Söke was founded on a peninsula, approximately 2.5 km long. In the Byzantine period, the city boundaries were quite reduced. The region was subjected to Turkish assaults after the battle of Malazgirt (1071) and gradually. In 1424 Miletus was taken inside of the Ottoman Empire and was completely abandoned in the 17$^{th}$ century. Excavation studies were first begun in 1899 for the Berlin museum and interrupted during the First World War. At present excavations and restoration works continue.

İlyas Bey Mosque and its complex buildings, situated to the south of the South Agora, constitute a complex with its Medrese and Baths. The Mosque built in 1404 by İlyas Bey, Emir of Menteseogullari founded in 1279 and named after him, is one of the most remarkable buildings of Miletus. The baths were built in the Roman period. Two main purposes of the study is (1) to determine archaeological remains of the study area and (2) to define the nature of main rock unit and their sources in the vicinity or Aegean region. Therefore we acquired GPR profile data paralleled each other in Ilyas Bey Mosque and its behind, left and right side, Courtyard and inner Courtyard of the Mosque. After processing 2D parallel GPR profiles, we constructed 3D data volume by lining processed 2D profiles up to correlate remain signatures from each profile for each studied area. We obtained transparent 3D visualisation of GPR data by assigning a new colour scale for the amplitude range and by constructing a new opacity function instead of the linear opacity function. Therefore we could successfully image the archaeological remains in an interactive transparent 3D volume and its sub-volumes**,** starting at different depth levels or limited profiles. The geological and mineralogical, petrographical studies reveal that the main bulding rock units of Miletus and ilyasbey Mosque are mainly composed of 4 main units these are marble, metalimestone, mica gneiss and granodiorite. The marble, metalimestone with the mica gneiss were obtained from Menderes Massif in Western Anatolia. The granodiorite columns might be obtained from Kozak pluton in the north of Bergama- izmir of western Anatolia.

## Migrations and adaptations of early *Homo* in western Turkey

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Turkey lies at the crossroads of the Old World and preserves evidence of numerous migrations of fossil mammals from Africa, Europe, and Asia. Some of the most interesting of these early migrations include the Miocene appearance of fossil apes, presumably originating in Africa, and horses, whose ancestry can be traced to North America; a much later migration is that of the genus *Homo* as documented by numerous archaeological sites dating from the Lower Paleolithic and onwards. It appears likely that these early events were mediated by a combination of tectonic and climatic controls including eustatic sea level changes. The much later appearance of the genus *Homo* has proven to be more enigmatic to understand because many of the 2 archaeological sites are not well dated. The recent discovery of the first specimen of early *Homo*, recovered from within a solid block of travertine rock quarried near Denizli in the Menderes basin, offers new information about the controls that limited the expansion of this group. The specimen dates to about 500 Ka and falls within Marine Isotope Stage 13, a warm interglacial that was preceded and followed by two of the coldest glacial stages of the past million years. This finding matches those for other fossil hominins from temperate settings and supports the hypothesis that the early range expansion of this tropically adapted group was controlled in part by glacial cycles. Furthermore, evidence that the Denizli hominin suffered from tuberculosis permits an investigation of the interplay between the reduced UVR of temperate regions and the biological adaptation of skin color. The discovery of the first early hominin from Turkey helps us to elucidate the factors that control the range expansion of this group. Given that the extensional basins of western Turkey preserve thick stratigraphic sections, these rocks hold great potential for the recovery of new fossils that will facilitate an even more detailed examination of these issues.

## Diverse P-T paths for the Cycladic ultramafic rock associations: constraints on their origin, emplacement and exhumation

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Within the Alpine orogen of the Cyclades ultramafic rocks occur in diverse tectonic positions, are associated with a variety of rock sequences and are regionally metamorphosed at variable conditions. Here this diversity is interpreted in terms of variable mechanisms for incorporation of mantle rocks into orogenic belts and used to better constrain spatial heterogeneity of P-T burial and exhumation paths in the Cyclades.  The Cycladic Blueschist Unit (CBU) was metamorphosed first at high pressure conditions in the Eocene (M1) and variably overprinted during exhumation in the Early Miocene (M2).  On the islands of Syros and Evia the CBU includes relatively thin HP-LT ophiolitic mélange intervals hosted by meta-sedimentary sequences. Meta-serpentinites are associated with eclogitized metagabbro and metabasites on Syros, but with epidote blueschists on Evia. Given the wide and comparable geochemical heterogeneity in the Syros and Evian mélanges, the Syros metabasites record higher M1 temperatures (450-500°C) relative to their Evian counterparts (400-430°C). The M2 overprint is manifested in Syros by greenschist facies assemblages (~450°C), whereas pumpellyite-actinolite assemblage (~350°C) overgrew blueschists in Evia. Within the M2 migmatized leucogneiss core of the Naxos dome (~700°C) meta-peridotite lenses are the sole preservers of pre-M2 history. The Naxos meta-peridotites possess relict mantle assemblage, fertile spinel lherzolite chemical composition and mantle-like oxygen isotope ratios. Thus unlike ophiolite-associated ultramafics in the Cyclades that were serpentinized prior to metamorphism, the Naxos metaperidotites were directly emplaced from the subcontinental mantle into an underthrust continent during collision and HP metamorphism. Ultramafic assemblages constrain M1 temperatures on Naxos to 550-650°C. It follows that going southeastwards from Evia through Syros to Naxos progressively deeper levels of the subducted plate are exposed. Correspondingly temperatures of the M2 overprint also increase. The diverse P-T paths of the CBU form an array wherein the deeper a rock sequence is buried, the 'hotter' is its exhumation path. Such a pattern is predicted by thermal modeling of tectonically thickened crust unroofed by either erosion or uniform extension.

## Relationships Between Crustal Structure and Extension in the Basin and Range Province and East Africa

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The Basin and Range Province of the western United States is an unusually wide continental rift zone, and its structure and evolution have been the topic of much debate. Large scale Cenozoic extension has exhumed midcrustal rocks (from 10-20 km depth) along low angle detachment faults to create metamorphic core complexes. In contrast to the extreme amounts of extension and internal deformation of the Basin and Range, the Colorado Plateau has remained a relatively rigid block, with a crustal thickness of 40-50 km that was resistant to Laramide compression and Basin and Range extension. Integrated studies undertaken using seismic refraction/wide-angle reflection, gravity, remote sensing, and geologic data have delineated a relatively uniform crustal thickness of 27-31 km within the Southern Basin and Range, 32-36 km thick crust in the Transition Zone, and 37-42 km thick crust in the southwesternmost Colorado Plateau. However, the velocity of the lower crust rarely exceeds 6.5 km/s indicating that mafic material is volumetrically insignificant. There are areas of thickened lower crust that correlate with regions of greatest extension (Death Valley, Lake Mead, and Colorado River extensional corridor) and the long wavelength (100-400 km) component of the Bouguer gravity anomaly field. The seismic velocity and density of these lower crustal features indicate that they are either intruded by mafic material, the result of the intrusion of intermediate composition rocks directly from the mantle or the result of lateral ductile flow. In contrast, the crust in along the Eastern arm of the East African rift varies greatly axially in a way that correlates with the amount of extension. Here and in the Main Ethiopian rift, the magmatic modification of the crust is significant, but the crustal column is still that of a modestly extended cratonal area. The magmatic modification of the crust is primarily mafic and correlates with volcanic events and features in a logical way.

## The unroofing history of Naxos and Paros: Constraints and questions from thermochronology and thermal modeling

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The Naxos/Paros extensional fault system (NPEFS) accommodated a significant portion of Miocene extension in the Aegean. The exposure is unusually complete, consisting of a thick lower-crustal ductile shear zone grading upwards into a thin, brittle detachment. Thermochronometric systems with closure temperatures documenting passage of the footwall through the brittle (apatite and zircon fission-track and (U-Th)/He) and ductile (hornblende K-Ar) zones provide important constraints on the unroofing history of this system. Brittle-zone slip rates based on fission-track data are generally in the 6-8 km/Myr range spanning times from 13-8 Ma, whereas inferred ductile-zone slip rates average ~5 km/Myr from 16-12 Ma. We used finite element thermal modeling to test the hypothesis that Naxos and Paros unroofed simultaneously and at similar rates, from ~16 Ma to ~8 Ma, with the only difference being a ~12 Ma granodiorite intrusion on Naxos. We found that a simplified model with uniform detachment fault dip (30°) and slip rate (6.5 km/Myr.) adequately explains all of the fission-track and some zircon (U-Th)/He data, although other (U-Th)/He data are problematic. The data are somewhat more fully reproduced if there was some acceleration during the latter stages of unroofing, but large uncertainties in slip rates preclude a firm conclusion. The thermal model also provides a reasonable mechanism for unifying inferred brittle-zone slip rates with slower ductile-zone ones, as the latter may have been rendered artificially low due to isotherm advance during the early stages of detachment faulting. At the same time, the modeling exercise forces a thorough assessment of the thermal budget of the crust before and during the initiation of detachment faulting. Other data have suggested that unroofing began as early as 20 Ma, and that early decompression was associated with heating. Insofar as unroofing is only in itself a cooling mechanism for the footwall, the source of this additional heat, and what happened to it, is a matter requiring further investigation before a complete picture of extension on the NPEFS can be formulated.

## Interaction between faulting, magma emplacement and volcanism in the central Aegean

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A distinct spatial relationship between surface faulting, magmatic intrusions and volcanic activity appears to exist in the deforming Aegean continental crust. These observations complemented by a detailed map of offshore faults, tectonic lineaments and structural analysis in onshore key areas enabled to improve our understanding for the interaction between tectonics and magmatic activity in the central Aegean. Middle Miocene granites seem to be strongly controlled by NNE-trending strike-slip faults and are placed along a composite NE-trending shear zone. Additionally, we provide evidence that linear arrangements of volcanic centers, from the three main late Quaternary volcanoes along the South Aegean Volcanic Arc, are controlled primarily by NE-striking faults and secondary NW-striking faults. These volcanic features are located in several structural settings such as, intersections of NE- and NW-trending faults, extensional step-over zones between echelon divergent strike-slip fault segments, and at the extensional quadrants of NE-trending shear zones. The NE-preferred strike of the volcano-tectonic features, such as cone alignments, concentration of eruptive centers, hydrothermal activity craters and fractures, indicate the significant role of tectonics in controlling fluid pathways in the eruptive centers. Furthermore, microseismicity and focal mechanism solutions of strong events in the area provide additional evidence for the recent activity and kinematics of the NE- and NW-trending faults.

Strike-slip motion along discrete NE-trending fault zones and extension seem to control the magmatic activity in the central Aegean and can decipher some aspects of the recent deformation in this area.

## Paleoseismic investigations along a key active fault within the Gulf of Corinth, Greece

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The study of paleoseismological and archaeological excavations provide clues for the evolution of a key active fault, the Helike Fault, which displays high activity and exerts control on the landscape, along the westernmost end of the Gulf of Corinth. In this study we present a series of paleoseismic trenches which revealed well defined fault strands and clear colluvial stratigraphy. We focus on the two main segments of the Helike Fault and their implications on strong earthquake activity. The Helike Fault is a major tectonic structure that influenced the evolution of ancient settlements on the Helike Delta, from the Early Bronze Age through the Byzantine period, till present times. The eastern fault segment appears to control the southern gulf morphology, while the western segment is controlling a large basin. Interbedded organic-rich soils and gravels dominate in all trenches. Fault strands that control successive scarp-derived colluvial deposits were identified within the trenches and indicate the continuous seismic activity along the fault trace. Co-seismic offsets, open cracks filled with debris and liquefaction related deformation was also recognized. Seven seismic events during the last 10 ka were identified inside the excavated trenches. The estimated vertical throw along the fault segments, observed within the trenches, is on the order of 1m per event. Based on dating of colluvial wedges we estimated the Holocene slip rate on the Helike Fault. We regard the derived slip rates as minimum values, due to the implication of erosional effects and sediment accumulation from the upthrown block. The Helike fault appears to play a crucial role both in subsidence of the Helike delta plain and shifting of the river course that runs between the two Helike fault segments. The clustering of surface rupturing events on the Helike fault seems to fit well with the subsidence of the Helike Delta plain and its change from marsh to lake or pod over the last 10 Ka.

## The accretionary model for orogenesis and its application to the evolution of the Aegean crust

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Both modern and ancient mountain belts have characteristic 'fingerprints' determined by the sequencing of the tectonic mode switches that took place during their evolution. In an orogen affected by tectonic mode switches, what happens is largely dependent on the magnitude and rate of lithospheric stretching or shortening before and after individual mode switches, and upon how rapidly motion was taking place, before and afterwards. These factors fundamentally influence the thermal evolution of an orogen, and thus directly or indirectly determine the processes that take place within it. For example, orogens affected by abrupt "push-pull" mode switches are characterized by high-pressure metamorphism whereas orogens affected by abrupt "pull-push" mode switches are characterized by high-temperature metamorphism, magmatism and anatexis.

This insight leads to different views as to the nature of orogenesis, and as to what distinguishes accretionary *versus* collisional orogens. For example consider the notion that orogens are constructed and that thereafter they collapse. This simple view can be refuted, in the process assigning terms such as "syn-orogenic" or "post-orogenic" to the dustbin. There can be several episodes during which an orogen is "constructed" just as there can be several episodes during which lithosphere-scale extension tears a newly created orogen apart, as is the case during Alpine orogenesis. Gravitational energy driven collapse of the orogen can occur continually throughout this process, and is not restricted to an artificially defined so-called post-orogenic phase.

Tethyan style orogenesis is characterized by a sequence of "push-pull" tectonic mode switches associated with the accretion of a succession of continental ribbons. The origin of the extensional episodes can be found in the driving forces provided by rapid "roll-back" of adjacent subducting slabs. Such slabs appear to be created during indentation triggered foundering of the marginal basins that typified ancient Tethys. We suggest individual accretion events were marked by short-lived episodes of high-pressure metamorphic mineral growth, followed by the development of km-scale extensional shear zones. The mode switches are often evident in tectonic sequence diagrams as F Δ SZ sequences, where F are recumbent folds, Δ a mineral growth episode, and SZ are extensional shear zones. Microstructures imply that mineral growth in the Δ events was static, or that they took place with such rapidity that deflections of fabric due to accumulating strain are not evident. Visually, the appearance of static growth was maintained.

In our examination of the Cycladic Eclogite-Blueschist Unit at least three separate F Δ SZ sequences have been documented. The evolution of the Aegean crust was thus marked by a complexity that will not be unravelled without modern microstructurally focussed geochronology, and geospeedometry, in particular using the $^{40}Ar/^{39}Ar$ isotopic system.

## Trace element geochemistry and isotopic composition of mafic and ultramafic cumulate xenoliths in alkaline basalts from the eastern Rhodopes, Bulgaria: Inferences on deep processes under the metamorphic core complexes

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Oligocene within-plate alkaline basalts and lamprophyres intruded in the Eastern Rhodope metamorphic core complexes, Kesebir and Biala Reka, carry a series of ultramafic and mafic xenoliths. Ultramafic xenoliths consist of dunites, websterites, olivine- and amphibole-bearing websterites, clinopyroxenites, and orthopyroxenites, whereas mafic xenoliths are represented by 2-pyroxene- and clinopyroxene gabbros, some of which show centimeter thick layering. These xenoliths are interpreted as samples of a layered intrusion formed at upper mantle-lower crustal depths.

Calculated parental liquids from LA ICP-MS analyses of clinopyroxene in ultramafic clinopyroxenites indicate that clinopyroxenites may have formed from melts with clear Nb and Ta positive anomalies, similar in composition to their host basanitic magma. The clinopyroxene REE patterns of the most mafic orthopyroxenite and olivine websterite suggest that they have also crystallized from an alkali-basaltic melt. The least magnesian websterites show flat to "W"-shape REE patterns with strong depletion in MREE, suggesting amphibole fractionation. Trace element compositions of gabbros and high-Fe clinopyroxenites and their melt inclusions indicate that these rocks are the most differentiated product from the same parent. Calculated parental liquids for some of them, however, show a significant difference from the host basanitic magma. The former are more enriched in REE, with pronounced Nb, Ta and Ti negative anomalies, on their Primitive-mantle normalized diagrams, as commonly observed for typical subduction-related rocks. Such transition from Nb-Ta-Ti enriched to Nb-Ta-Ti depleted magma can be related to fractionation of amphibole, the only phase which is characterized by high compatibility of these elements.

Sr and Nd isotopic compositions of a differentiated websterites and a gabbro are more radiogenic than those of the host basanites, demonstrating an apparent contradiction with suggested basanite-like parental magma. This contradiction can be reconciled by a model of crustal contamination of the basanitic magma with more radiogenic lower crustal material.

Thus, the entire compositional continuum of the xenoliths is the result of concomitant fractionation in the presence of amphibole and lower crustal contamination.
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## Constraints on Replenishment, Magma Mixing, and Crystal Recycling Processes at Santorini Volcano, Greece

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Santorini is the largest volcanic centre in the Aegean arc, with an eruptive history spanning more than 250,000 years over two eruptive cycles. The cycles are dominated by extended periods of effusive shield-building activity with occasional large-magnitude explosive eruptions, the Minoan eruption of ~3600 years ago being the most recent. Current activity consists of a phase of post-caldera reconstruction, focused on the intra-caldera Kameni islands.

Santorini represents an ideal system in which to study magma chamber dynamics and open-system processes such as magma replenishment and crystal recycling. The large, rhyodacitic pyroclastic deposits typically contain a mafic component. Microsampling to measure $^{87}Sr/^{86}Sr$ isotope ratios of plagioclase cores from both the silicic and mafic components suggests the presence of a complex plumbing system beneath Santorini, with the coexistence of isotopically distinct magma batches. To add further complexity, plagioclase phenocrysts are in some cases in equilibrium with their groundmass, while others show the reverse, implying modification of the replenishing magmas by crystal recycling or shallow mixing processes prior to eruption.

Mafic enclaves in the recent Kameni lavas, interpreted as the probable eruption trigger, provide some constraints on the rates of these recycling, mixing, and triggering processes. Glomerocrysts and xenocrysts of recycled gabbroic cumulate material are present in a number of Kameni enclaves. Isotopic and chemical disequilibrium between the cumulate crystals and the enclave host indicate that these fragments are derived from pre-existing crystal mush piles pervaded by the replenishing melts as they migrated to shallow levels. In response to disequilibrium between the cumulate material and the replenishing, cumulate olivine xenocrysts in the enclaves develop narrow (10-30 μm) Fe-Mg diffusion profiles where they are in contact with enclave magma groundmass. The width of these diffusion rims can then be used to estimate the interval between entrainment and eruption. Initial modelling of diffusion profiles from more than 30 crystals suggests short timescales, from 1 to 3 months, for the combined magma migration-replenishment-eruption cycle at Kameni. Such information may prove useful in terms of volcanic hazard prediction and mitigation in the future.

## Thrusts and extensional detachments within the Cretan tectonostratigraphy

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The tectonostratigraphic nappe pile of Crete is analysed with special emphasis on the distinction of the complex term "phyllites – quartzites" in several tectonic units. Thus, from the lower carbonate rocks of the relative autochthon unit of Mani (or Metamorphosed Ionian) to the upper carbonate rocks of the Tripolis carbonate platform there is a number of tectonic units within the schistose type formations, such as: i) The metamorphic flysch of the Mani unit, of Oligocene age. ii) The complex metamorphic unit of Western Crete, comprising late Paleozoic schists, early – middle Triassic evaporites and late Triassic- early Jurassic marbles (Trypali). iii) Medium-grade HP/LT metamorphic rocks of the Arna unit (known from equivalent rocks in Peloponnesus). iv) The Permo-triassic volcanosedimentary base of the Tripolis platform, comprising phyllites, metasandstones, volcanic rocks and some carbonate layers, known as the Ravdoucha Beds (equivalent of the Tyros Beds in Peloponessus) together with evaporites and Variscan high-grade metamorphic rocks of the Sitia unit. The Ethia unit (equivalent of the Pindos unit in continental Greece) is observed overthrusting the Tripolis unit and then a number of small nappes occurring in topmost position are exposed in various small outcrops usually in the form of tectonic klippen all over Crete. These higher nappes are: i) The Arvi unit, comprising late Cretaceous basalts and pelagic sediments. ii) The Miamou unit, comprising a late Cretaceous wildflysch. iii) The Vatos unit, comprising late Paleozoic – Triassic sedimentary sequence. iv) The Cretan ophiolitic nappe. v) The Asteroussia nappe, comprising high-grade metamorphic rocks and granites with a late Cretaceous age of metamorphism. The primary tectonic contacts of the above tectonic units are thrusts, which can be observed in numerous outcrops given on our tectonic map of Crete. The age of thrusting ranges between late Eocene in the higher nappes to early Miocene in the lower nappes. Secondary tectonic contacts representing extensional detachments occur in several places. These low-angle normal faults do not follow a certain tectonic contact but several planes of anisotropy representing both primary thrusts and stratigraphic boundaries. The age of the extensional detachments is Middle Miocene and it is related to the syntectonic sediments of breccia-conglomerates (e.g. the Prina complex). High-angle normal and strike-slip faults dissect and disrupt the previous structure of thrusts and extensional detachments and they are in most cases active structures. Nevertheless, some segments of former detachments are still active today. The outcrops of the late Miocene – Pliocene marine sediments show the subsiding blocks during this period. The general uplift of Crete during Quaternary marks the present-day deformation.

## Death Valley turtlebacks: Mesozoic contractional structures overprinted by Cenozoic extension and metamorphism beneath syn-extensional plutons

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The term turtleback was first coined to describe the curvilinear fault surfaces that produced a distinctive geomorphic form in the Black Mountains east of Death Valley, and although it was decades before their full significance was appreciated, they remain one of the most distinctive features of the extensional structure of the Death Valley region. Historically the interpretation of the features has varied markedly, and misconceptions about their character continue to abound, including descriptions in popular field guides for the area. It the 1990's, however, the full history of the systems began to be apparent from several key data: 1) the dating of the plutonic assemblage associated with the turtlebacks demonstrated that late Miocene, syn-extensional plutonism was fundamental to their formation; 2) the plutonic assemblage forms an intrusive sheet structurally above the turtlebacks, indicating a tie between much of the high grade metamorphism and Cenozoic plutonism; 3) a modern analog for the syn-extensional plutonism in the Black Mountains was recognized beneath Death Valley with the imaging of a mid-crustal magma body; 4) the Neogene structural history was worked out in the turtlebacks showing that folding of early-formed shear zones formed the turtleback anticlinoria but overprinting by brittle faults produced the final form as they cut obliquely across the older structure; and 5) the pre-extensional structural history was clarified, demonstrating that Mesozoic basement-involved thrust systems are present within the turtlebacks, but have been overprinted by the extensional system. An unresolved issue is the significance of Eocene U-Pb dates for pegmatites within the region, but presumably these relate somehow to the pre-extensional history. Miller and Pavlis (2005; E. Sci. Rev.) reviewed many features of the turtlebacks,and our working model for the region is that the turtlebacks originated as mid-crustal ductile-thrust systems within the Cordilleran fold-thrust belts. Our work to the east of Death Valley suggests these thrusts were part of a NW trending thrust system that overprinted an older NE trending fold-thrust system that tracks into the Death Valley region from Nevada. These NW trending thrusts probably underlie all of the southern Black Mountains (south of the turtlebacks) and we suggest that pre-extensional structural relief along these basement thrusts placed basement at shallow crustal levels throughout what is now the Black Mountains; a conclusion consistent with the absence of rocks younger than Cambrian beneath Tertiary unconformities throughout the southern Death Valley region. In Late Miocene time, a major detachment system formed and the turtlebacks represent a mid-crustal shear zone developed during that time period, but this system is older, and structurally beneath younger detachments systems that comprise the Amargosa fault system. During motion on the detachment, an ~2km thick plutonic sheet was emplaced along the shear zone forming the Miocene plutonic assemblages of the Black Mountains, and produced upper amphibolite facies metamorphic assemblages along the floor of the pluton in what are now the Copper Canyon and Mormon Point turtlebacks, but the Badwater Turtleback escaped this metamorphism due to a different structural position. Motion continued along the floor of the pluton but syn-extensional folding produced structural relief along folds with axes parallel to the extension direction. Ultimately a new detachment system cut obliquely across the older extensional system, removing the roof of the pluton, but cutting down to its floor in the turtlebacks. This fault system formed a complex detachment system updip in the famous "Amargosa Chaos", and removing the entire cover sequence from the Black Mountains (~10-12km of crustal section). The turtlebacks are therefore a composite structure in which extension contemporaneous with folding, presumably as a result of distributed transcurrent motion during extension, was critical to their formation. In addition, syn-tectonic plutonism played a key role in strain localization and metamorphism within the assemblages that comprise the turtlebacks.

## Post-collisional deformation of the Anatolides and motion of the Arabian indenter: a paleomagnetic analysis

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In the Anatolides of Turkey the neotectonic (post collisional) phase of deformation embraces the period since final closure of the southern arm of Neotethys in mid-Miocene times. The Arabian Shield indenter has continued to deform into the weak Anatolian accretionary collage resulting from subduction of this ocean by a combination of differential movement relative to the African Plate and counterclockwise (CCW) rotation. Much of resulting deformation has been accommodated by slip along major transforms comprising the North Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ) and the northward extension of the Dead Sea Fault Zone (DSFZ) but has also been distributed as differential block rotations through the zone of weak crust in between. Facets of this deformation comprise crustal thickening and uplift to produce the Anatolian Plateau, establishment of transform faults and tectonic escape as Arabia has continued to impinge into the Anatolian collage. Paleomagnetic analysis of this deformation is facilitated by the widespread distribution of neotectonic volcanism and graben infills, and rotations relative to the Eurasian reference frame are recognised on two scales. Rapid rotation (up to 5°/10,000 years) of small fault blocks is identified between master faults along the intracontinental transforms but deformation does not extend away from these zones and shows that seismogenic upper crust is decoupled from a lower continental lithosphere undergoing continuum deformation. The broad area of weak accreted crust between the transforms is dissected into large fault blocks which exhibit much lower rotation rates (mostly <1°/100,000 years) that vary systematically across the Anatolides. Large CCW rotations near the Arabian indenter diminish westwards to become zero then CW near the limit of tectonic escape in western Turkey. The view that the collage has rotated anticlockwise as a single plate, either uniformly or episodically, during the Neotectonic era is refuted. Instead, deformation has been distributed and differential as the collage has adapted to changing tectonic regimes. Crustal extrusion to the west and south has expanded the curvature of the Tauride Arc and combined with retreat of the Hellenic Arc to produce the extensional horst and graben province in western Turkey. A challenge of present work is to resolve the temporal framework of tectonic rotation. Evidence from the Cappadocian volcanic province and Sivas Basin in central Anatolia indicates that rotation has been concentrated within the last 2-3 million years of the neotectonic era and therefore correlates with establishment of the intracontinental transform

framework. Thus we recognise two phases to the evolution of this sector of the orogen: the first embraces crustal thickening and uplift with initiation defined specifically by transition from marine to terrestrial deposition in the Serravallian at ~12 Ma, and the second embraces crustal extrusion to the west motivated by continuing northward movement of Arabia and roll back on the Hellenic Arc since late Pliocene times. Latitudinal motions detected by paleomagnetism are close to confidence limits and consistent with small northward motion of the Anatolides since Eocene times including up to a few hundred km of closure linked to crustal thickening since the demise of NeoTethys. The driving motion from the Arabian indenter can be partially resolved from the widespread basaltic volcanism that occurred along the periphery of the Arabian Shield at 12-18 Ma during final stages of collision along the Bitlis Suture. This defines CCW rotation of 13-21° with respect to Eurasia. An average CCW rotation of 0.9°/Myr since closure of the Bitlis Suture in mid-Miocene times is unlikely to have been uniform because it has been linked to three adjoining interactions namely episodic opening of the Red Sea, a transition from crustal thickening to tectonic escape in the Anatolian collage and variable rates of strike slip motion on the DSFZ.

## Orogenic vs anorogenic lamproites in a single volcanic province: lamproites from Turkey

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Lamproites are mantle-derived volcanic rocks characterized by severe enrichment in incompatible trace-elements combined with variable and extreme radiogenic isotope compositions. General agreement exists that a normal four-phase peridotitic mantle cannot represent their source, because a metasomatic K-rich hydrous mineral, in most models phlogopite, is required. The origin of the metasomatism which enriched their mantle source is, however, a confusing issue, as lamproites typically have a very "ancient" isotopic signature which cannot always be related to known tectonic events: it is either an old event with a metasomatic component derived from the convecting mantle, or is a more recent introduction of an already aged metasomatic component. This view serves ultimately for a general distinction between anorogenic and orogenic lamproites.

In Turkey, lamproitic volcanism resulted from interplay of subduction/collisional and postcollisional/extensional regime since Miocene until Pliocene, in the Western Anatolia-Aegean and Kırka-Afyon-Isparta region. We will present new set of Ar-Ar age data together with geochemical data, including Sr, Nd, Pb and Hf isotopes, of all Turkish lamproites. Our study revealed the most intriguing geochemical data: although the majority of lamproites have an orogenic affinity, with radiogenic $^{87}Sr/^{86}Sr$, $^{207}Pb/^{204}Pb$, and unradiogenic $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$, and high LILE/HFSE ratios, the lamproites from the most southern localities (Bucak area) exhibit geochemical features characteristic for anorogenic lamproites, with unradiogenic $^{87}Sr/^{86}Sr$, $^{207}Pb/^{204}Pb$, and radiogenic $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$, coupled with rather smooth incompatible trace element pattern with low LILE/HFSE ratios and high concentrations of Nb and Ti. The common and coeval occurrence of anorogenic and orogenic lamproites in a single volcanic province suggests that geodynamic distinction of lamproites based only on geochemistry may be questioned.

In our contribution we will discuss the role of upper crust and convecting mantle source in the origin of Turkish lamproites, on order to present and evaluate a model which may explain their unusual geochemistry. Unique interplay of postcollisional geodynamics and specific mantle metasomatism, provide a suitable environment where such volcanism may take place.

## Geodetic constraints on present-day deformation of the Aegean extensional region, Greece and western Turkey: Implications for active tectonics

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Geodetic monitoring of regional deformation of the Aegean Extensional Province was initiated in 1988 in both the Aegean Sea region of Greece, and the adjacent extensional region of westernmost Turkey. Monitoring has proliferated since then via international cooperative projects using both survey, and continuous GPS observations. In westernmost Turkey, the predominant mode of deformation is ~ N-S extension, consistent with the roughly E-W striking basin and range structures there, and well observed earthquake focal mechanisms. Active extension across western Turkey exceeds 15 mm/yr. In contrast, a major part of the Aegean Sea, including the south central, and southwestern Aegean, and the Peloponnesus is characterized by coherent, trench-ward motion with internal deformation below 2 mm/yr (i.e., ~5% of the rate of motion of the Aegean with respect to Nubia or Eurasia). While the very low rate of deformation in this area is consistent with the low level of historic seismic activity, it needs to be reconciled with the clear evidence for Aegean extension in the geologic record. We suggest a scenario where distributed extension of the southern Aegean became focused along the North Aegean Trough (NAT) when the North Anatolian fault (NAF) extended across the Aegean from NW Turkey and connected with active N-S extension across the Gulf of Corinth (GoC). This essentially decoupled the S Aegean from Eurasia and allowed the S Aegean to translate to the south with active extension being concentrated in the NAT and GoC. The timing of this possible extension of the NAF across the NAT is not well constrained, but some recent geologic observations in the Marmara Sea region suggest this may have occurred in the past few 100 thousand years (Sengor et al., 2005).

The largest deformation of the S Aegean involves trench-ward extension in the southeastern corner, including eastern Crete and Rhodes. Extension reaches 15 mm/yr at Rhodes, immediately adjacent to the deepest segment of the Hellenic Trench system. Perhaps surprisingly, we find very little evidence for contraction along the leading edge of the over-riding Aegean "plate" as would be required if strain is accumulating along the subduction interface. While the low level of strain would appear to imply little strain accumulation and hence little likelihood of future major subduction-type earthquakes, this interpretation is complicated by uncertainties about the location and geometry of the subduction interface, and equivocal geologic evidence for a large, prehistoric, tsunami-generating event near W Crete.

## The 365 AD earthquake and tsunami: Implications for tectonics and tsunami hazard of the Eastern Mediterranean

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The 21 July, 365 AD earthquake was widely recorded in the historical record, and was followed by a devastating tsunami, which drowned thousands of people in coastal regions from the Nile delta to modern-day Dubrovnik. Here we present new radiocarbon data and field observations which show that the western Crete was lifted, up to 10 m above sea-level, synchronously with the AD 365 earthquake. Uniquely for the Mediterranean, we can use measurements of the palaeosea-level to determine a set of faults which could have caused the uplift. This uplift pattern, combined with present day seismicity, suggest that the earthquake occurred not on the main subduction interface beneath Crete, but on a fault which dips more steeply and reaches the surface closer to Crete, coinciding with the major bathymetric escarpment known as the Hellenic Trench. Calculations of tsunami propagation show that uplift of the sea floor along such a fault would have generated a damaging tsunami through much of the eastern Mediterranean, consistent with what we know of the tsunami from the historical record. Measurement of the present rate of crustal shortening near Crete yields an estimate of ~5000 years for the repeat time of similar events on this single fault, and this estimate is supported by evidence from much older uplifted terraces. If the same process takes place along the whole length of the Hellenic subduction zone, such events may occur approximately once every 800 years.

## Metamorphic Style and Development of the Blueschist- to Eclogite-Facies Rocks, Cyclades, Greece

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The rocks of the island of Syros are part of the Attic-Cycladic blueschist belt, formed during Mesozoic Eurasia-Africa subduction. The rocks of Syros can be broadly divided into three tectono-stratigraphic units: (I) metamorphosed sedimentary and volcanic rocks, (II) remnants of oceanic crust with faultbounded packages of blueschist/eclogite-facies mafic rocks and serpentinite and (III) the Vari gneiss, which is a tectonic klippe. Low-temperature, high-pressure assemblages are found on several islands in the Cyclades. The best preserved of these rocks are on Syros and Sifnos. Mineral compositions and peak metamorphic assemblages are similar on both islands. Both islands are considered to share similar P-T histories with high-pressure mineral assemblages reflecting conditions of at least 15 kbar and about 500°C. However, constraining the P, T and deformation histories of Syros and Sifnos is a work in progress with many contributors. The high-pressure assemblages in this part of the Cyclades all show a later greenschist-facies overprint of varying local intensity and duration. Because of the variety of rock types found on Syros, a number of unusual metamorphic features occur. These features include glaucophanebearing marbles, which are rare among descriptions of high-pressure marbles and high-pressure metasomatic zones formed between juxtaposed metasedimentary, mafic and ultramafic protoliths. The glaucophane + $CaCO_3$ stability is sensitive to fluid composition and suggests a water-rich attending fluid phase with $XCO_2 < 0.03$. On Syros, much of the calcite in marbles shows oriented columnar structures interpreted as pseudomorphs of prismatic aragonite, but fossils are found at few places. Within the northern Syros mélange zone, detailed study of one metasomatic sequence at the contact of a glaucophaneepidote-
phengite-garnet schist (volcanoclastic ptotolith) and serpentinite showed development of zones of glaucophane + epidote + chlorite; chlorite + sphene; omphacite + epidote + chlorite ± tourmaline and chlorite ± rutile ± apatite, along with accessory phases at pressures of ~6–12 kbar. The fluid compositions and hybrid metasomatic assemblages reported here could have significance beyond the context of the Aegean as constraints on elemental and fluid compositions recycled to the mantle.

## Know your Rigid Indenter: An Overview of the Continental Crust and Lithosphere of the Arabian Plate

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There are 2 main reasons for students of Aegean tectonics to be interested in the continental crust of the Arabian Plate: 1) Since the early Pliocene, the Anatolian plate has extruded west as the result of rigid indenting by the Arabian Plate. The Arabian plate is currently moving NW at 2 cm/yr, and sinistral slip on the East Anatolian Fault is about 1 cm/yr. Because of this and the southward migration of the Aegean arc over old oceanic crust beneath the eastern Mediterranean, Aegean lithosphere is extending and moving south. 2) Paleozoic rifting of northern Africa and Arabia may have moved significant tracts of ANS-type crust northward, forming nuclei around which parts of Aegean and Anatolian crust may have coalesced. Arabian indenter upper crust is buried as much as 10 km near the collision zone but is exposed as the Arabian Shield, which formed during Neoproterozoic time (870-542 Ma) and similar crust can be inferred from geophysics to enter the collision zone. Buried crust imaged in Syria and Jordan suggest a possible Neoproterozoic suture and Phanerozoic stable blocks and intervening mobile zones, similar to that exposed in the Arabian shield. Arabian plate continental crust shows similar thicknesses everywhere (~35-45 km) except around its margins, where it thins noticeably. It often shows a well-defined mid-crustal "Conrad" velocity step, separating felsic upper crust from mafic lower crust. Xenolith suites indicate that the upper lithospheric mantle is composed of spinel peridotite whereas the lower crust is composed of pyroxene-rich metagabbro. Nd isotopic data indicate that spinel peridotite and mafic lower crust formed during Neoproterozoic time, consistent with ages and isotopic compositions of exposed upper crust of the Arabian Shield. This further indicates that Arabian continental upper and lower crust and mantle lithosphere formed as a coherent column as a result of Neoproterozoic extraction of juvenile crust as melt from the mantle and efficient differentiation of juvenile crust into mafic lower and felsic upper layers, with minor subsequent modifications except for thinning due to Phanerozoic rifting. The lack of quartz in deep continental crust of the Arabian implies that the middle and lower crust are strong and that a strong mid-crustal decollement should not be expected to exist in that part of Arabia that is colliding with eastern Anatolia.

## Integrated thermochronometric and structural constraints on the exhumation of the western Cycladic metamorphic core complexes

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Geodynamic models for the Cenozoic development of back-arc extension in the Aegean are largely based on constraints from the eastern Cyclades, while our understanding of the tectonic evolution of the western Cyclades is only basic. The absence of detailed structural, kinematic, and temporal constraints on extensional faulting in the western Cyclades has made it difficult to evaluate and test these different geodynamic models of the Aegean realm. While most of the central and western Cyclades (e.g., Naxos) were dominated by top-to-the-NNE directed, large-magnitude extension in the middle to late Miocene, the eastern Cyclades accommodated opposite sense, top-to-the-SSW crustal extension, resulting in the formation of low-angle normal faults on Kea, Kythnos, and Serifos. Our integrated structural and geo- and thermochronometric study of the western Cycladic domain has revealed that crustal extension occurred in multiple stages or in a protracted fashion since early Cenozoic times and potentially significantly earlier than in rest of the Cyclades. On Serifos, structural, metamorphic, and geo-/thermochronological constraints demonstrate that top-to-SSW middle to upper crustal extensional detachment faulting occurred pre- to synmagmatically in the late Miocene. These extensional structures are similar to low-angle normal faults discovered on Kythnos and Kea and cross-cut earlier top-to-SSW mid-crustal high strain zones. To constrain the thermal and exhumational evolution of these extensional complexes in the western Cyclades, we commenced an ambitious sampling campaign for $^{40}Ar/^{39}Ar$ mica and zircon and apatite (U-Th)/He thermochronometry (>80 samples). These high-density thermochronometric sample arrays, both parallel and perpendicular to the extensional slip direction, on Kea, Kythnos, and Serifos will help constrain the timing, rates, spatial distribution, and magnitude of extensional faulting and footwall exhumation since the early Miocene and refine geodynamic models for the entire Cycladic realm of the Aegean. Preliminary thermochronometric data corroborate that the western Cyclades accommodated major top-to-the-SSW directed extension in middle to late Miocene time with opposite sense to the NNE-directed Hellenic nappe stacking and detachment kinematics of the eastern Cyclades.

## Geomorphic Response of an Active Metamorphic Core-Complex in a Collisional Orogen: Example from the Lunggar Shan, Southern Tibet

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We present structural and neotectonic mapping from the Lunggar Shan rift in southern Tibet. The Lunggar Shan is a N-trending mountain range ~70 km long N-S and up to 40 km wide E-W. The Lunggar Shan is bounded on its east side by a low-angle (<40°) east-dipping detachment fault that juxtaposes mylonitic gneiss and variably deformed granites in its footwall against alluvial fans and Neogene gravels in its hangingwall. Foliations in the mylonitic footwall dip <40° east and stretching lineations are east plunging. The range front detachment is presently inactive as indicated by undisturbed moraines and Quaternary sediments that overlie it. However, we consider the Lunggar Shan detachment to be an active structure, as inferred by range parallel fault scarps cutting Quaternary alluvium located 4-5 km into the hangingwall basin, with >40 m of throw on individual scarps. An intriguing observation is that an intrabasinal topographic high is actively developing near areas of inferred maximum extension, with lacustrine sediments being uplifted and eroded. This observation indicates that the rift basin initially developed as a typical half-graben system that underwent a transition from deposition, to uplift and erosion perhaps as a result of isostatic rebound of the footwall at depth, warping the overlying hangingwall basin. If correct, the Lunggar Shan may represent a modern analogue to the supradetachment basin model.

## Tectonic block rotation, arc curvature and back-arc rifting: insights into these processes in the Mediterranean and western Pacific

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The fastest modern-day tectonic block rotations (up to 9 degrees/Myr) occur in the forearcs of convergent plate margins where a transition from collision to subduction occurs (Wallace et al., 2005). GPS techniques have enabled accurate documentation of the kinematics of these rotations, leading us to develop a conceptual model where the change from collision to subduction exerts a torque on microplates within the plate boundary zone, causing them to spin rapidly about an axis at the collision point. We think such a model is highly relevant to the active tectonics of the Mediterranean. We have investigated geophysical and geological data from 23 active and ancient plate boundaries (largely from the western Pacific and Mediterranean regions) to document a compelling spatial and temporal relationship between the transition from collision to subduction, plate boundary curvature, and rapid tectonic block rotations. In some cases, these microplate rotations can lead to or greatly modify the kinematics of back-arc rifting.

We also present numerical modelling results supporting our conceptual model for block rotations at the collision/subduction transition. Our results suggest that the rate of microplate rotation depends on the incoming indentor velocity, and can be greatly enhanced by: (1) extensional stresses acting at the subduction interface (possibly due to slab roll back), and (2) a low-viscosity back-arc. Where viscosity of the back-arc is low, forearc microplate rotation dominates, while tectonic escape behaviour occurs in models where the back-arc viscosity is high.

The kinematics of the Anatolian block probably represents some combination of these two end-members.

Previous workers have suggested that the kinematics of the Anatolian block and back-arc rifting in the Aegean are influenced by some combination of forces associated with Arabia/Eurasia collision, and/or subduction (and possible slab rollback) at the Hellenic trench. We suggest that our model for microplate rotation at the transition from collision to subduction (developed from a number of western Pacific examples) is highly relevant to understanding mechanisms behind the large-scale tectonic rotation and escape of Anatolia, the kinematics of deformation in the Aegean, and paleomagnetic evidence for rapid rotation of western Greece. The recognition of several global analogues for Mediterranean active tectonics may lead to new insights into the dominant forces behind tectonic processes there.

## The Bodrum Magmatic Centre, SW Anatolia; Its Tectonic and Volcanic Significance in the Geology of the Aegean Region

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The Magmatic activities occurred in Western Antolia discontinuously from the Oligocene to the present. Among the magmatic activities two episodes may readily be distinguished as interior phases: a) the late Oligocene- Middle Miocene phase, b) late Miocene- Pliocene Phase. During the older phase a number of granite plutons were intruded as exemplified from the Kozak, Ezine and Kestanbul areas. The plutons are surrounded by geochemically related, and partially co-eval plutonic and volcanic rocks. Their spatial and temporal relations lead to assume that they were formed in a caldera collapse environment. This magmatic activitiy produced predominantly intermediate to the felsic magmatic rocks. Following a brief non-volcanic interval the younger magmatic stage began which produced sporadically developed basaltic lavas. They were absent in the previous phase.

The morphotectonics of theWestern Anatolia is dominated by a number of E-W trending grabens intervened by thin and long horst blocks. Field and seismic data obtained from these structures confirm that they have been formed under a N-S extension. However, the older magmatic centres are aligned in NNE-SSW trending structures, and form volcanic highs, lying parallel to the surrounding grabens. They both are cut abruptly by the present E- W trending grabens.

The Bodrum Magmatic Centre is situated at the South western corner of the Anatolian Peninsula. This magmatic centre shows many resemblances to the older Magmatic Centres; it was built as a result of the products of two magmatic phases. During the first phase temporarily and spatially associated, plutonic and volcanic rocks of intermediate and felsic composition were formed. The second phase produced basic dykes and lavas. Time of initiation and development of the Bodrum Magmatic Complex corresponds approximately to the non volcanic interval recorded between the development of two Magmatic phases observed further north. Therefore, development of the Bodrum Magmatic Complex is critical in our understanding of tectonics versus magmatism within the Aegean geology. Details of the Bodrum Magmatic Complex and its tectonic significance in Western Anatolia will be discussed in this presentation.

## Mechanics of Non-Andersonian Conjugate Strike-Slip Faults in Active Collisional Orogens: Observations, Theories and Implications for Laterally Moving Asthenospheric Flow

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Formation of conjugate strike-slip faults is commonly explained by the Anderson fault theory, which predicts a X-shaped conjugate fault pattern with an intersection angle of ~30 degrees between the maximum compressive stress and the faults. However, major conjugate faults in Cenozoic collisional orogens, such as the eastern Alps, western Mongolia, eastern Turkey, northern Iran, northeastern Afghanistan, and central Tibet, contradict the theory in that the conjugate faults exhibit a V-shaped geometry with intersection angles of 60-75 degrees, which is 30-45 degrees greater than that predicted by the Anderson fault theory. In Tibet and Mongolia, geologic observations can rule out bookshelf faulting, distributed deformation, and temporal changes in stress state as explanations for the abnormal fault patterns. Instead, the GPS-determined velocity field across the conjugate fault zones indicate that the fault formation may have been related to Hagen-Poiseuille flow in map view involving the upper crust and possibly the whole lithosphere based on upper mantle seismicity in southern Tibet and basaltic volcanism in Mongolia. Such flow is associated with two coeval and parallel shear zones having opposite shear sense; each shear zone produce a set of Riedel shears, respectively, and together the Riedel shears exhibit the observed non-Andersonian conjugate strike-slip fault pattern. We speculate that the Hagen-Poiseuille flow across the lithosphere that hosts the conjugate strike-slip zones was produced by basal shear traction related to asthenospheric flow, which moves parallel and away from the indented segment of the collisional fronts. The inferred asthenospheric flow pattern below the conjugate strike-slip fault zones is consistent with the magnitude and orientations of seismic anisotropy observed across the Tibetan and Mongolian conjugate fault zones, suggesting a strong coupling between lithospheric deformation and asthenospheric flow. The laterally moving asthenospheric flow may have been driven by the converging cratons with thick mantle lithosphere. This may have caused the shallow asthenosphere below a region sandwiched between the cratons to be squeezed out laterally.