Organic Geochemistry 12.491 MW 11-12:30 Rm 54-1510

In this course we will evaluate and discuss the formation and diagnostic structural properties of organic matter with particular emphasis on chemical fossil potential. The topics to be covered include:

- biological and non-biological formation of organic matter
- isotopic compositions of naturally occurring organic compounds
- the classification and chemical structures of biomarkers
- biomarker relationships to organism physiology and phylogeny
- preservation potential and mechanisms; diagenesis, kerogen formation and hydrocarbon generation
- analytical techniques used to study biomarkers and kerogen
- paleoreconstruction using biomarkers

Each week's effort will comprise a Monday overview lecture (1-1.5 hrs) and set readings. The Wednesday session will be a group discussion of the readings. In these discussions, participants will present a synopsis and critique of one of the readings.

Two term papers will be required for 50% of the credit. The remaining 50% will be awarded on the basis of contribution to the weekly literature critique.

Week 1 Sept 3 (Summons)

Introductory remarks; course structure and content.
Biogenicity: Factors that might discriminate biological from non-biological organic matter. Abiological OM formation; meteorites.

Week 2 Sept 8 & 10 (Hayes)

Stable Isotopes I. Fractionation of carbon isotopes during carbon assimilation and lipid biosynthesis.

Week 3 Sept 15 & 17 (Hayes)

Stable Isotopes II. Fractionation of the isotopes of H and N. Carbon-14 in modern systems.

Week 4 Sept 22 & 24 (Summons)

Acetogenic lipids and their fossil counterparts; chain-length, branching systematics and isotopic compositions - indicators of biological sources; algeanans; functional roles; geological patterns of occurrence.

Week 5 Sept 29 & Oct 1 (Summons)

Isoprenoid lipids; biosynthesis; isomerism and other structural aspects; archaeal and non-archaeal sources; structure *vs* physiology; bicyclic and tricyclic isoprenoids; other cyclised polyprenoids; geological record.

Week 6 Oct 6 & 8 (Summons)

Steroids; biosynthetic issues; formation by bacteria and eukaryotes; role of oxygen. sterol to sterane diagenesis; biomarkers for source and maturity in fossil OM; age-related changes in occurrence and paleoenvironmental indicators

Week 7 Oct 13 (Columbus Day) 15 (Love and Hebting)

Kerogen; experimental approaches to classification and structural analysis; Rock Eval; pyrolysis and chemical degradation.

Week 8 Oct 20 & 22 (Summons)

Mono-, sesqui-, di- and triterpenoids 1; biosynthetic issues; bacteria and eukaryotes; Bacteriohopanepolyols; analytical issues; phylogeny & physiology *vs* structure; BHP to hopane diagenesis; biomarkers for source, maturity of OM

Week 9 Oct 27 & 29 (Summons)

Diterpenoids and Triterpenoids 2; plant-derived terpenoids; biomarkers for age and environmental assessment.

First term paper due. Biosynthetic controls on isotopic and molecular biosignatures.

Week 10 Nov 3 & 5 (Grosjean & Brocks) Seattle GSA week

Pigment-derived biomarkers; porphyrins and carotenoids

Week 11 Nov 10 & 12 (Summons)

More on diagenesis and catagenesis; OM preservation; kerogen formation. Role of reduced sulfur.

Week 12 Nov 17 & 19 (Summons)

Complex lipids and characterization of extant microbes. Microbial mat communities; lipids and biogeochemical cycles within mats.

Week 13 Nov 24 & 26 (Summons)

Characterization of fossilised OM; bitumen; oil and gas; coal; resinites; amber. Hydrocarbon generation.

Week 14 Dec 1 & 3 (Summons)

The ancient record. Examples of paleoreconstruction using structural and compound-specific isotopic data

Term paper #2 Due. Geochemical and geological approaches to reconstructing the nature of microbial communities, present and past.

Week 15 Dec 8 & 10 (Summons); Fall AGU week

Archaeological applications of biomarkers.

Organic Geochemistry Readings:

Texts:

Engel M.H. and Macko S.A. (1993) (Eds) *Organic Geochemistry Principles and Applications*, Plenum Press, New York.

Hayes J. M. (2001) Fractionation of the isotopes of carbon and hydrogen in biosynthetic processes. In: *Stable Isotopic Geochemistry*, Valley J. W. and Cole D.R. (eds.) *Reviews in Mineralogy and Geochemistry* **43**, 225-278.

Peters K. E. and Moldowan J. M. (1993) *The Biomarker Guide*. Prentice Hall.

Optional: Gold T. (2001) *The Deep Hot Biosphere : The Myth of Fossil Fuels*. Freeman Dyson.

Week 1 Biogenic vs Abiogenic

Anders E. (1989) Pre-biotic organic matter from comets and asteroids. *Nature* **342,** 255-257.

Bada J.L., Cronin J.R., Ho M.-S., Kvenvolden K.A., Lawless J.G., Miller S.L., Oro J., and Steinberg S. (1983) On the reported optical activity of amino acids in the Murchison meteorite. *Nature* **301**, 494-497.

Cronin J.R., and Pizzarello S. (1997) Enantiomeric excesses in meteoritic amino acids. *Science* **275**, 951-955.

Engel M.H. and Macko S.A. (1997) Isotopic evidence for extraterrestrial non-racemic amino acids in the Murchison meteorite. *Nature* **389**, 265-268.

McCollom T.M. (2003) Formation of meteorite hydrocarbons from thermal decomposition of siderite. *Cosmochim. Acta* **67**, 311-317.

Pizzarello S. and Cronin J.R. (2000) Non-racemic amino acids in the Murchison and Murray meteorites. *Geochim. Cosmochim. Acta* **64**, 329-338.

Sephton M.A., and Gilmour I. (2001) Compound specific isotope analysis of the organic constituents in carbonaceous chondrites. *Mass Spectrometry Reviews* **20**, 111-120.

Sephton M.A. (2002) Organic compounds in carbonaceous meteorites. Natural Products Reports 19, 292-311.

Week 2 Isotopics 1

Hayes, J. M. (2001) Fractionation of the isotopes of carbon and hydrogen in biosynthetic processes. pp. 225-278 in John W. Valley and David R. Cole (eds.) *Stable Isotope Geochemistry*, *Reviews in Mineralogy and Geochemistry* Vol. 43. Mineralogical Society of America, Washington, D. C. (2001). pdf available at http://www.nosams.whoi.edu/general/jmh/index.html To avoid saturation, skim from the beginning to the section headed "Isotopic Compositions of Carbohydrates." Study that section. Skip "Isotopic Compositions of Amino Acids" and everything else up to "Isotopic compositions of Lipids," which *should* be studied.

Hayes, J. M. and Sessions, A. L. (2002) Edited teaching notes, especially sections 2.3 "Isotope effects," and 2.4 "Isotopic fractionations." Available for downloading as IsoNotesAug02.pdf at http://www.nosams.whoi.edu/general/jmh/index.html

Laws, E. A., Popp, B. N., Bidigare, R. R. Kennicutt, M. C., and Macko, S. A. (1995) Dependence of phytoplankton carbon isotopic composition on growth rate and $[CO_2]_{aq}$: Theoretical considerations and experimental results. *Geochim. Cosmochim. Acta.* **59,** 1131-1138.

Week 3 Isotopics 2

Eglinton T. I., Benitez-Nelson B. C., Pearson A., McNichol A. P., Bauer J. E., and Druffel E. R. M. (1997) Variability in radiocarbon ages of individual organic compounds from marine sediments. *Science* **277**, 796-799.

Pearson, A., McNichol, A. P., Benitez-Nelson, B. C., Hayes, J. M. and Eglinton, T. I. (2001) Origins of lipid biomarkers in Santa Monica Basin surface sediment: A case study using compound-specific ?^{14}C analysis. *Geochim. Cosmochim. Acta* **65**, 3123-3137.

Sessions, A. L., Burgoyne, T. W., Schimmelmann, A. and Hayes, J. M. (1999) Fractionation of hydrogen isotopes in lipid biosynthesis. *Organic Geochemistry* **30**, 1193-1200.

Sigman, D. M. and Casciotti, K. L. (2001) Nitrogen isotopes in the ocean. pp. 1884-1894 in *Encyclopedia of Ocean Sciences*, J. H. Steele, K. K. Turekian, and S. A. Thorpe (eds.). Academic Press, London.

Week 4 Acetogenic Lipids

Allard B., Rager M.-N., and Templier J. (2002) Occurrence of high molecular weight lipids (C_{80+}) in the trilaminar outer cell walls of some freshwater microalgae. A reappraisal of algaenan structure. *Org. Geochem.* **33**, 789-801.

Blokker P., Schouten S., de Leeuw J. W., Sinninghe Damsté J. S., and van den Ende H. (2000) A comparative study of fossil and extant algaenans using ruthenium tetroxide degradation. *Geochim. Cosmochim. Acta* **64**(12), 2055-2065.

Blokker P., Schouten S., van den Ende H., de Leeuw J. W., Hatcher P. G., and Sinninghe Damsté J. S. (1998) Chemical structure of algaenans from the fresh water algae *Tetraedron minimum*, *Scenedesmus communis* and *Pediastrum boryanum*. *Org. Geochem.* **29**(5-7), 1453-1468.

Blokker P., van Bergen P. F., Pancost R. D., Collinson M. E., Sinninghe Damsté J. S., and de Leeuw J. W. (2001) The chemical structure of *Gloeocapsamorpha prisca* microfossils: implication for their origin. *Geochim. Cosmochim. Acta* **65**, 885-900.

Derenne S. and Largeau C. (2001) A review of some important families of refractory macromolecules: composition, origin and fate in soils and sediments. *Soil Science* **166**, 833-847.

Gelin F., Boogers I., Noordeloos A. A. M., Sinninghe Damsté J. S., Riegman R., and de Leeuw J. W. (1997) Resistant biomacromolecules in marine microalgae of the classes Eustigmatophyceae and Chlorophyceae: geochemical implications. *Org. Geochem.* **26**(11-12), 659-675.

Höld I. M., Schouten S., Jellema J., and Sinninghe Damsté J. S. (1999) Origin of free and bound mid-chain methyl alkanes in oil, bitumens and kerogens of the marine, Infracambrian Huqf Formation (Oman). *Org. Geochem.* **30**, 1411-1428.

Kenig F. (2000) C_{16}-C_{29} homologous series of monomethylalkanes in the pyrolysis products of a Holocene microbial mat. *Org. Geochem.* **31**, 237-241.

Rieley G., Collister J. W., Stern B., and Eglinton G. (1993) Gas chromatography/ isotope ratio mass spectrometry of leaf wax n-alkanes from plants of differing carbon dioxide metabolisms. *Rapid Communications in Mass Spectrometry* **7**, 488-491.

Summons R. E. and Walter M. R. (1990) Molecular fossils and microfossils of prokaryotes and protists from Proterozoic sediments. *Am. J. Sci.* **290-A**, 212-244.

Tegelaar E. W., de Leeuw J. W., Derenne S., and Largeau C. (1989) A reappraisal of kerogen formation. *Geochim. Cosmochim. Acta* **53**, 3103-3106.

Wharton B., Alexander R., and Kagi R. I. (1997) Identification of some single branched alkanes in crude oils. *Org. Geochem.* **27**, 465-476.

Week 5 Acyclic Isoprenoids

Kates M. (1993) Membrane lipids of Archaea. In *The Biochemistry of Archaea (Archaebacteria)* (ed. M. Kates, K. D. J, and A. T. Matheson), pp. 261-295. Elsevier Science.

Sinninghe Damsté J. S., Rijpstra W. I. C., Hopmans E. C., Prahl F. G., Wakeham S. G., and Schouten S. (2002) Distribution of membrane lipids of planktonic Crenarchaeota in the Arabian Sea. *Applied and Environmental Microbiology* **68**, 2997-3002.

Tornabene T. G., Langworthy T. A., Holzer G., and Oro J. (1979) Squalenes, phytanes and other isoprenoids as major neutral lipids of methanogenic and thermoacidophilic archaebacteria. *J. Mol. Evol.* **13**, 73-83.

Volkman J.K and Maxwell J.R. (1986) Acyclic isoprenoids as biological markers: In: Biological Markers and the Sedimentary Record (ed R.B. Johns). Elsevier NY. P1-42.

Woese C. R., Kandler O., and Wheelis M. L. (1990) Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya. *Proc. Natl. Acad. Sci. USA* **87**, 4576-4579.

Michaelis W., Seifert R., Nauhaus K., Treude T., Thiel V., Blumenberg M., Knittel K., Gieseke A., Peterknecht K., Pape T., Boetius A., Amann R., Jørgensen B. B., Widdel F., Peckmann J., Pimenov N. V., and Gulin M. B. (2002) Microbial reefs in the Black Sea fueled by anaerobic oxidation of methane. *Science* **297**, 1013-1015.

Thiel V., Peckmann J., Seifert R., Wehrung P., Reitner J., and Michaelis W. (1999) Highly isotopically depleted isoprenoids: molecular markers for ancient methane venting. *Geochim. Cosmochim. Acta* **63**(23/24), 3959-3966.

Week 6 Steroids et al.

Brassell S.C, Eglinton G. and Maxwell J.R. (1983) The geochemistry of triterpenoids and steroids. Biochemical Society Transactions 11, 575-586. (photocopy).

Dahl J., Moldowan J.M., Summons R.E., McCaffrey M.A., Lipton P.A., Watt D.S. and Hope J.M., 1995, Extended 3b-alkyl steranes and 3-alkyl triaromatic steroids in oils and rock extracts. *Geochimica et Cosmochimica Acta* **59**, 3717-3729. (VERA)

Huang W.-Y. and Meinschein W.G. (1979) Sterols as ecological indicators. Geochem.Cosmochim Acta 43, 739-745. (Photocopy).

Jahnke L. L. and Klein H. P. (1979) Oxygen as a factor in eukaryote evolution: some effects of low levels on *Saccharomyces cerevisiae*. *Origins of Life* **9**, 329-334.

Jahnke L. L. and Klein H. P. (1983) Oxygen requirements for formation and activity of the squalene epoxidase in *Saccharomyces cerevisiae*. *J. Bacteriol.* **155**(2), 488-492.

McCaffrey M.A., Moldowan J.M., Lipton P.A., Summons R.E., Peters K.E., Jeganathan A. and Watt D.S., 1994, Paleoenvironmental implications of novel C_{30} steranes in Precambrian to Cenozoic age petroleum and bitumens. *Geochimica et Cosmochimica Acta* **58**, 529-532. (Libr)

Moldowan J. M., Dahl J., Jacobson S. R., Huizinga B. J., Fago F. J., Shetty R., Watt D. S., and Peters K. E. (1996) Chemostratigraphic reconstruction of biofacies: molecular evidence linking cyst-forming dinoflagellates with pre-Triassic ancestors. *Geology* **24**, 159-162.

Summons R.E., Thomas J., Maxwell J.R.and Boreham C.J., 1992, Secular and environmental constraints on the distribution of dinosterane in sediments. *Geochimica et Cosmochimica Acta* **56**, 2437-2444.

John K. Volkman, Stephanie M. Barrett, Susan I. Blackburn, Maged P. Mansour, Elisabeth L. Sikes and François Gelin (1998) Microalgal biomarkers: A review of recent research developments,*Organic Geochemistry 29*, 1163-1179. (VERA)

Volkman JK (2003) Sterols in microorganisms. Applied Microbiology and Biotechnology 60, 495-506. (VERA)

Finding good papers that pertain to the oxygen dependence of sterol biosynthesis, and why sterols are good indicators of aerobic processes, gets you bonus marks.

Week 7 Kerogen structure and analysis (Love & Hebting)

Love

Gelinas, Y., Baldock, J.A. and Hedges, J.I. (2001) Organic carbon composition of marine sediments: Effect of oxygen exposure on oil generation potential. Science 294 (5540), 145-148.

Hold, I.M. et al (1994) Recognition of n-alkyl and isoprenoid algaenans in marine sediments by stable carbon isotopic analysis of pyrolysis products of kerogens. Organic Geochemistry 22 (3-5), 543-574.

Tegelaar E. W., de Leeuw J. W., Derenne S., and Largeau C. (1989) A reappraisal of kerogen formation. *Geochim. Cosmochim. Acta* **53**, 3103-3106.

Hebting

Adam et al., direct link to the pdf:
http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V66-41CP1JG-4-17&_cdi=5806&_orig=search&_coverDate=10%2F31%2F2000&_qd=1&_sk=999359979&view=c&wchp=dGLbVlbzSkzk&_acct=C000022659&_version=1&_userid=501045&md5=50e176c7c65095d9becccfb58044b1e0&ie=f.pdf

Wakeham S. G., Sinninghe Damsté J. S., Kohnen M. E. L., and de Leeuw J. W. (1995) Organic sulfur compounds formed during early diagenesis in Black Sea sediments. *Geochim. Cosmochim. Acta* **59**, 521-533.
direct link to the pdf:
http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V66-3YYTKHJ-BH-1&_cdi=5806&_orig=search&_coverDate=02%2F28%2F1995&_qd=1&_sk=999409996&view=c&wchp=dGLbVzz-zSkWA&_acct=C000022659&_version=1&_userid=501045&md5=1d2fab3ff6db0cf4670ec2cec89b3b05&ie=f.pdf

Kohnen M. E. L., Sinninghe Damsté J. S., Baas M., Kock-van Dalen A. C., and de Leeuw J. W. (1993) Sulphur-bound steroid and phytane carbon skeletons in geomacromolecules: implications for the mechanism of incorporation of sulphur into organic matter. *Geochim. Cosmochim. Acta* **57**, 2515-2528.
http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V66-41CP1JG-4-17&_cdi=5806&_orig=search&_coverDate=10%2F31%2F2000&_qd=1&_sk=999359979&view=c&wchp=dGLbVlb-zSkzk&_acct=C000022659&_version=1&_userid=501045&md5=50e176c7c65095d9becccfb58044b1e0&ie=f.pdf

Adam et al., not online
Tetrahedron Letters (1991), 32(25), 2955-8

Week 8 Cyclic terpenoids 1

Ourisson G. and Albrecht P. (1992) Hopanoids 1. Geohopanoids: the most abundant natural products on Earth? *Accounts of Chemical Research* **25**, 398-402.

Ourisson G., Rohmer M., and Poralla K. (1987) Prokaryotic hopanoids and other polyterpenoid sterol surrogates. *Ann. Rev. Microbiol.* **41**, 301-333.

Rohmer M., Bouvier-Navé P., and Ourisson G. (1984) Distribution of hopanoid triterpenes in prokaryotes. *J. Gen. Microbiol.* **130**, 1137-1150. (photocopy).

Rohmer M., Knani M., Simonin P., Sutter B., and Sahm H. (1993) Isoprenoid biosynthesis in bacteria: a novel pathway for the early steps leading to isopentenyl diphosphate. *Biochem. J.* **295**, 517-524.

Summons R.E. and Jahnke L.L., 1990, Identification of the methylhopanes in sediments and petroleum. *Geochimica et Cosmochimica Acta* 54, 247-251.

Helen M. Talbot, Diane F. Watson, Emma J. Pearson and Paul Farrimond (2003) Diverse biohopanoid compositions of non-marine sediments. *Organic Geochemistry* 34, 1353-1371.

Thiel V., Blumenberg M., Pape T., Seifert R., and Michaelis W. (2003) Unexpected occurrence of hopanoids at gas seeps in the Black Sea. *Organic Geochemistry* 34, 81-87.

Week 9 Cyclic terpenoids 2 incl. plants; age diagnostic biomarkers

Grantham P. J. and Douglas A. G. (1980) The nature and origin of sesquiterpenoids in some Tertiary fossil resins. *Geochim. Cosmochim. Acta* **44**, 1801-1810.

Noble R. A., Alexander R., and Kagi R. I. (1986) Identification of some diterpenoid hydrocarbons in petroleum. *Org. Geochem.* **10**, 825-829. (photocopy).

Noble R. A., Alexander R., Kagi R. I., and Knox J. (1985) Tetracyclic diterpenoid hydrocarbons in some Australian coals, sediments and crude oils. *Geochim. Cosmochim. Acta* **49**, 2141-2147.

Moldowan J. M., Dahl J. E. P., Huizinga B. J., Fago F. J., Hickey L. J., Peakman T. M., and Taylor D. W. (1994) The molecular fossil record of oleanane and its relation to angiosperms. *Science* **265**, 768-771.

Murray A.P., Sosrowidjojo I.B., Alexander R., Kagi R.I., Norgate C.M. and Summons R.E., 1997, Oleananes in oils and sediments: evidence of marine influence during early diagenesis? *Geochimica et Cosmochimica Acta* **61**, 1261-1276.

ten Haven H. L., Peakman T. M., and Rullkötter J. (1992) Early diagenetic transformation of higher-plant triterpenoids in deep-sea sediments of Baffin Bay. *Org. Geochem.* **56**, 2001-2024. (photocopy).

Week 10 Pigment-related biomarkers (Grosjean & Brocks)

Sinninghe Damsté J. S., Schouten S., and van Duin A. C. T. (2001) Isorenieratene derivatives in sediments: possible controls on their distribution. *Geochim. Cosmochim. Acta* **65**, 1557-1571.

Additional references to be provided by Emma and Jochen

Week 11 Diagenesis and catagenesis; role of oxygen, reduced sulfur and water

Kliti Grice, Stefan Schouten, Arie Nissenbaum, Josef Charrach and Jaap S. Sinninghe Damsté (1998) A remarkable paradox: Sulfurised freshwater algal (Botryococcus braunii) lipids in an ancient hypersaline euxinic ecosystem, *Organic Geochemistry* 28, 195-216. (VERA).

Hebting, Y., P. Adam, and P. Albrecht, 2003, Reductive desulfurization of allylic thiols by HS/H_2S in water gives clue to chemical reactions widespread in natural environments: Organic Letters v.5, p.1571-1574. (VERA)

Kohnen M. E. L., Schouten S., Sinninghe Damsté J. S., de Leeuw J. W., Merrit D. A., and Hayes J. M. (1992) Recognition of paleobiochemicals by a combined molecular sulphur and isotope geochemical approach. *Science* **256**, 358-362.

Math E. L. Kohnen, Stefan Schouten, Jaap S. Sinninghe Damsté, Jan W. de Leeuw, Dawn Merrit and J. M. Hayes. (1992) The combined application of organic sulphur and isotope geochemistry to asses multiple sources of palaeobiochemicals with identical carbon skeletons.*Organic Geochemistry 19, 403-419.* (photocopy).

M. D. Lewan and T. E. Ruble (2002) Comparison of petroleum generation kinetics by isothermal hydrous and nonisothermal open-system pyrolysis, *Organic Geochemistry* 33, 1457-1475. (VERA)

Lewan M. D. (1997) Experiments on the role of water in petroleum formation.*Geochim. Cosmochim. Acta* 61(17), 3691-3723.

Murray A.P., Sosrowidjojo I.B., Alexander R., Kagi R.I., Norgate C.M. and Summons R.E., 1997, Oleananes in oils and sediments: evidence of marine influence during early diagenesis? *Geochimica et Cosmochimica Acta* **61**, 1261-1276.

Jean-François Rontani and John K. Volkman (2003) Phytol degradation products as biogeochemical tracers in aquatic environments, *Organic Geochemistry* 34, 1-35.
(VERA)

Carolyn M. Sandison, Robert Alexander, Robert I. Kagi and Christopher J. Boreham (2003) Early diagenetic transformation of organic matter in a marine-influenced lignite,*Organic Geochemistry* 34, 1081-1102. (VERA)

Week 12 Complex lipids of bacteria, eukarya and archaea; microbial mats; biogeochemical cycles

Hoehler TM,. Bebout BM & Des Marais DJ (2001) The role of microbial mats in the production of reduced gases on the early Earth Nature 412, 324 – 327.

Search for other articles on gases that can serve as a biomarker eg O2, CH4, H2

Linda L. Jahnke, Tsege Embaye, Janet Hope, Kendra A. Turk, Mark van Zuillen, David J. Des Marais, Jack D. Farmer and Roger E. Summons (2003) Lipid Biomarker and Carbon Isotopic Analyses of Stromatolite-Forming, Microbial Mat Communities and *Phormidium* cultures from Yellowstone National Park. Geobiology, submitted. (photocopy).

Kuypers M. M. M., Blokker P., Erbacher J., Kinkel H., Pancost R. D., Schouten S., and Sinninghe Damsté J. S. (2001) Massive expansion of marine Archaea during a Mid-Cretaceous Oceanic Anoxic Event. *Science* **293**, 92-94.

Kuypers M. M. M., Sliekers O. A., Lavik G., Schmid M., Jørgensen B. B., Kuenen J. G., Sinninghe Damsté J. S., Strous M., and Jetten M. S. M. (2003) Anaerobic ammonium oxidation by anammox bacteria in the Black Sea. *Nature* **422**, 608 - 611.

S. T. Petsch, K. J. Edwards and T. I. Eglinton (2003) Abundance, distribution and 13C analysis of microbial phospholipid-derived fatty acids in a black shale weathering profile, *Organic Geochemistry* 34, 731-743

Schouten S., Wakeham S. G., Hopmans E. C., and Sinninghe Damsté J. S. (2003) Biogeochemical evidence that thermophilic archaea mediate the anaerobic oxidation of methane. *Applied and Environmental Microbiology* **69**, 1680-1686.

Sinninghe Damsté J. S., Strous M., Rijpstra W. I. C., Hopmans E. C., Geenevasen J. A. J., van Duin A. C. T., van Niftrik L. A., and Jetten M. S. M. (2002) Linearly concatenated cyclobutane lipids form a dense bacterial membrane. *Nature* 419, 708-712.

Ward, D.M., J. Shiea, Y.B. Zeng, G. Dobson, S. Bassell, and G. Eglinton. 1989. Lipid biochemical markers and the composition of microbial mats, p. 439-454. *In* Y. Cohen and E. Rosenberg, (ed.). Microbial Mats: Physiological Ecology of Benthic Microbial Communities. American Society for Microbiology, Washington, D.C.

Week 13 Kerogen, bitumen, oil and gas, coal and resin

Boreham CJ, Hope JM & Hartung-Kagi B. 2001. Understanding source, distribution and preservation of Australian natural gas: A geochemical perspective. APPEA Journal 41, 523–547. (photocopy).

Mango F. D. (1991) The stability of hydrocarbons under the time-temperature condition of petroleum genesis. *Nature* **352**, 146-148.

Murray A.P., Edwards D., Hope J.M., Boreham C.J., Alexander R. and Summons R.E., 1998, Carbon isotope biogeochemistry of plant resins and derived hydrocarbons. *Organic Geochemistry* **29**, 1199-1214.

Price L. C. (1993) Thermal stability of hydrocarbons in nature: limits, evidence, characteristics, and possible controls. *Geochimica et Cosmochimica Acta* **57**, 3261-3280.

Price L. C. and Wenger L. M. (1992) The influence of pressure on petroleum generation and migration as suggested by aqueous pyrolysis. *Organic Geochemistry* **19**, 141-159.

.

Schoell, M., 1983, Isotope techniques for tracing migration of gases in sedimentary basins: Journal of the Geological Society, London, v. 140, p. 415-422.

Week 14 Paleoreconstruction with biomarkers

Brassell, S.C., I.T. Marlowe, G. Eglinton, U. Plaumann and M. Sarnthein (1986). Molecular stratigraphy: a new tool for climatic assessment. *Nature* 320, 129-133.

Eglinton G. and Calvin M. (1967) Chemical fossils. *Scientific American* **261**, 32-43.

Eglinton G., Scott P. M., Belsky T., Burlingame A. L., and Calvin M. (1964) Hydrocarbons of a biological origin from a one-billion-year-old sediment. *Science* **145**, 263-264.

Huang, Y., Street-Perrot, F.A, Perrot, R.A., Metzger, P. and Eglinton, G., 1999. Glacial-interglacial environmental changes inferred from the molecular and compound-specific delta13C analyses of sediments from Sacred Lake, Mt. Kenya. Geochimica et Cosmochimica Acta 63, 1383-1404

Marlowe, I.T., S.C. Brassell, G. Eglinton and J.C. Green (1990). Long-chain alkenones and alkyl alkenoates and the fossil coccolith record of marine sediments. *Chemical Geology* 88, 349-375.

Jaap S. Sinninghe Damsté and Stefan Schouten (1997) Is there evidence for a substantial contribution of prokaryotic biomass to organic carbon in Phanerozoic carbonaceous sediments? *Organic Geochemistry* 26, 517-530

Stefan Schouten, Marcel J. L. Hoefs and Jaap S. Sinninghe Damsté (2000) A molecular and stable carbon isotopic study of lipids in late Quaternary sediments from the Arabian Sea, *Organic Geochemistry* 31, 509-521.

Kai-Uwe Hinrichs, Laura R. Hmelo, Sean P. Sylva (2003) Molecular Fossil Record of Elevated Methane Levels in Late Pleistocene Coastal Waters. *Science* 299, 1214-1217.

Week 15 Archaeological and Forensic applications

S A Buckley, A W Stott and R P Evershed (1999) Studies of organic residues from ancient Egyptian mummies using high temperature-gas chromatography-mass spectrometry and sequential thermal desorption-gas chromatography-mass spectrometry and pyrolysis-gas chromatography-mass spectrometry. Analyst 124, 443-452.

Stephen A. Buckley, Richard P. Evershed (2001) Organic chemistry of embalming agents in Pharaonic and Graeco-Roman mummies. *Nature* 413, 837 – 841.

R P Evershed, S N Dudd, S Charters, H Mottram, A W Stott, A Raven, P F van Bergen and H A Bland. Lipids as carriers of anthropogenic signals from Prehistory. Phil. Trans. R. Soc. 354, 19-31.

Rapid screening of banknotes for the presence of controlled substances by thermal desorption atmospheric pressure chemical ionisation tandem mass spectrometry. R Sleeman, I Fletcher, A Burton, J F Carter and D J Roberts. Analyst 124, 1999, 103-108