#### U.S. DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY



SYNOPSIS OF THERMAL MATURITY PATTERNS IN ALASKA This map was produced from nearly 10,000 vitrinite-reflectance and CAI

This map was produced from nearly 10,000 virinite-reflectance and CAI terminations from surface, offshore, and subsurface localities across the state. From these ta, a number of generalities can be made. For example, rocks exposed at the surface of e Tertiary interior basins and in the Aleutian foreare and backatre basins are uniformly of ry low thermal maturity, indicating that these basins are at or near maximum burial, have en little upilift, and are probably thermally immature with respect to hydrocarbon nearation. In contra st, many sedimentary basins—for example, the Yokon-Koyukuk and generation. In contra st, many sedimentary basins—inor example, the Tokon-Koyukuk and Colville Basins—show elevated levels of thermal maturity at the surface, commonly with the highest values at basin margins. This geometry suggests a pattern of greater uplifa long basin margins, possibly reflecting isostatic readjustments as crustal loads are removed by

errosion. Johnsson and others (1993) investigated thermal maturity relations in three sedimentary basins—the Colville, Cook Inlet, and Kandik Basins—in more detail. Thermal maturity patterns in the Colville Basin are broadly asymmetric, suggesting systematic differential uplift ranging from a minimum of no uplift at the Arctic coastline to 9 to 13 km of uplift in the central Brooks Range; even greater uplift further to the south is indicated by the presence of greenschist facies and higher grade metamorphism. This Johnsson and other. (1993) investigated thermal maturity relations in them acdimentery basing. Them ers (1993) investigated thermal maturity relations in three sedimentary basins—the lville, Cook Inlet, and Kandik Basins—in more detail. Thermal maturity patterns in the lville Basin are broadly asymmetric, suggesting systematic differential unlift rameino Colville, Look Inlet, and Kandik Basins—in more detail. Inermail maturity patterns in the Colville Stain are broadly asymmetric, suggesting systematic differential uplift ranging from a minimum of no uplift at the Arctic coastline to 9 to 13 km of uplift in the central Brooks Range; even grater uplift further to the south is indicated by the presence of greenschist facies and higher grade metamorphism. This pattern may reflect the deflexing of the lithosphere subsequent to the principal episode(s) of crustal convergence and thickening. The continuity of this pattern across the region suggests a similar thermal history for the principal Phases of thrusting. In contrast, isograds in the foothills belt to the north are broadly warped by local structure, indicating continued north-south shortening (parallel to the strike of the oregen), a feature that to date has not been included in regional (parallel to the strikes of the oregen), a feature that to date has not been included in regional (parallel to the strikes) the oregen), a feature that to date has not been included in regional tectonic syntheses. Alternatively, this thermal-maturity pattern could be explained by tectonically unrelated uplift episodes in the eastern and western parts of the Brooks Range. In the Cook Intel Basin, vitrinite-reflectance isograd also are indicative of relatively

tectonically unrelated uplift episodes in the eastern and western parts of the Brooks Range. In the Cook Inlet Basin, virinitie-reflectance isograds also are indicative of relatively greater uplift at the basin margins than at the basin center. The basin center appears to be presently at its maximum burial depth. Uplift in the Cook Inlet Basin may reflect compression along the faults bounding the basin. High thermal maturity along the western margin of the basin also may reflect magmatic heat sources from the Alaska Peninsula-Aleutian Volcanic Arc. The Seldovia Arch, a major structural feature trending across the southern end of the basin (see Johnsson and others, 1993), does not appear to deform virinite-reflectance isograds, implying that deformation on that structure ceased prior to maximum burial (Johnsson and others, 1993). In the Kandik Basin, a thermal-maturity anomaly-thermally mature younger rocks in

In the Kandik Basin, a thermal-maturity anomaly—thermally mature younger rocks in foult contact with thermally limmature older rocks—provides clues to the nature and timing of east-west thrusting. Mesozoic foreland basin deposits associated with thrusting buried Paleozoic rocks of the eastermost part of this fold-and-thrust het to relatively shallow depths, driving potential hydrocarbon source rocks into the oil-generation window. The western foreland basin deposits were overridden by advancing thrusts and tectonically buried to as deep as 10 km. These disparate thermal domains are juxtaposed along the Glenn Creek Fault, which may represent a terrane boundary in east-central Alaska (Johnsson and others, 1993). Although complicated by the effects of convective heat transfer by fluids and spatial variations in heat flow, thermal maturity data from sedimentary rocks isolated from inenoous

variations in heat flow, thermal maturity data from sedimentary rocks isolated from igneous activity largely reflect burial heating and thus provide a means of assessing vertical movements in the upper crust. Thermal-maturity patterns in Alaska reflect the complex tectonic history of the region. The amalgamation of terranes with different thermal and the second secon olift histories produces a patchwork of sharply contrasting thermal maturity. Sedimentary asins developed on these terranes record the history of terrane accretion through ferential regional uplift. A varied thermal-maturity pattern in these deposits indicates a mplex pattern of uplift that is not readily apparent from traditional mapping of

### ACKNOWLEDGMENTS We would like to express our sincere thanks to all of those individuals who have ontributed unpublished data or samples to this project. Special thanks are extended to A.G.

contributed unpublished data or samples to this project. Special thanks are extended to A.G. Harris, who made available her complete Alaskan inventory of Conodont Color Alteration Index data, and to M.L. Miller, A. Anderson, R.R. Reifenstuhl, H.A. Cohen, S.E. Box, W.W. Patton, Jr., J.M. Murphy, and R.G. Stanley, who provided samples from critical areas. M.J. Pawlewicz produced hundreds of vitrinic reflectance determinations. L.B. Magoon was instrumental in organizing data collected over the past decade by USGS workers, and C.N. Threlkeld oversaw database management during submittal of new worker of the last of the part of the state of the database management during submittal of new sources, the USAS samples. X.J. Bird's familiarity with North Stope geology and the USAS sampling program proved invaluable in analyzing the data. Both L.B. Magoon and K.J. Bird also helped to solicit data from industry sources. Generous contributions of unpublished data were provided by the Shell Oil Company, British Petroleum, and Chevron. C. Dusel-Bacon made provided by the Shell Oil Company, British Petroleum, and Chevron. C. Dusel-Bacon made available her then unpublished metamorphism. Z.C. Valin extracted hundreds of vitrinite reflectance determinations from industry reports and the literature; he and C.F. Hamilton also assisted with data input. Assistance in the field was provided by M.B. Underwood, D.L. Gautier, C.J. Schenk, T. Brocculeri, L. Hudfu, P.B. O'Sullivan, W. Arendt, P. McClung, N. Fehri, F. Roure, and P. Desegauk, P.A. Swaka, V.A. Berghar, C.A. with computational aspects of data manipulation was provided by C.H. Degnan, C.A. with computational aspects of data manipulation was provided by C.H. Degnan, C.A. Madison, R.C. Obuch, M.J. Rachlitz, C.K. Runge, R. Sanders, and W.S. Weber. D.S. Aitkin, B.S. Bennet, T.T. Fitzgibbon, D.L. Knifong, P.K. Showalter, W.C. Steele, C.M. Wentworth, Jr., and F.L. Wong provided valuable advice on geographical information systems. This map benefited from critical reviews by K.J. Bird, S.E. Box, D.C. Bradley, J.L. Clayton, C. Dusel-Bacon, H.L. Foster, P.J. Haeussler, J.S. Kelley, L.B. Magoon, M.L. Miller, C.G. Mull, J.M. Murphy, G. Plarker, A.B. Till, and F.H. Wilson.

## REFERENCES CITED

Open-File Report 83-826, 17 p. Barker, C.E., and Pawlewicz, M.J., 1986, The correlation of vitrinite reflectance with

Marki, C.L., and Fawrewicz, M.J., 1950, The Contention Of vitinite fenetuatice with maximum paleotemperature in humic organic matter, *in Bunebarth*, G., and Stegena, L., eds., Paleogeothermics: New York, Springer-Verlag, p. 79–93. Jostick, N.H., 1979, Microscopic measurement of the level of catagenesis of solid organic matter in sedimentary rocks to aid exploration for petroleum and to determine former burial temperatures—A review, *in Scholle*, P.A., and Schluger, P.R., eds., Aspects of Diagenesis: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists Snevid Publication 26 n. 17 40. Special Publication 26, p. 17–44. Burnham, A.K., and Sweeney, J.J., 1989, A chemical kinetic model of vitrinite

maturation and reflectance: Geochimica et Cosmochimica Acta, V. 53, p. 2,699–2,657.
Epstein, A.G., Epstein, J.B., and Harris, L.D., 1977, Conodont color alteration—An index to organic metamorphism: U.S. Geological Survey Professional Paper 995, 27 p.
Héroux, Y., Chagnon, A., and Bertrand, R., 1979, Compilation and correlation of major v. 63, p. 2,128-2,144. Hood, A., Gutjahr, C.C.M., and Heacock, R.L., 1975, Organic metamorphism and the

59, p. 986-996. hnsson, M.J., Howell, D.G., and Bird, K.J., 1993, Thermal maturity patterns in Alaska: Implications to tectonic evolution and hydrocarbon potential: American Association of Petroleum Geologists Bulletin, v. 77, p. 1.874-1.903. Price, L.C., 1983, Geologic time as a parameter in organic metamorphism and vitrinite Price, L.C., 1983, Geologic time as a parameter in organic metamorphism and vitrinite reflectance as an absolute paleogeothermometer: Journal of Petroleum Geology, v. 6, or 5.29

p. 5-38. Rejebian, V.A., Harris, A.G., and Huebner, J.S., 1987, Conodont color and textural alteration: An index to regional metamorphism, contact two molt example alteration: An index to regional metamorphism, contact two molt examples hydrothermal alteration: Geological Society of America Bulletin, v. 99, p. 471–479. of Economic Paleontologists and Mineralogists Special Publication 26, 443 p. Stach, E., Mackowsky, M., Teichmuller, M., Taylor, G.H., Chandra, D., and Teichmuller, R., 1982, Stach's textbook of coal petrology: Berlin, Gebruder Borntreger, 535 p. weeney, J.J., and Burnham, A.K., 1990, Evaluation of a simple model of vitrinite reflectance based on chemical kinetics: America Bulletin, v. 74, p. 1,559–1,570.

MISCELLANEOUS INVESTIGATIONS SERIES MAP I-24 BULLETIN 2142 PLATE 1

#### SOURCES OF DATA

Data for this map have been compiled from the literature cited below, unpublished industry reports provided to the Alaska Division of Geological and Geophysical Surveys, previous USGS investigations, data contributed by industry, academic and government colleagues, and by our own sampling and analysis where needed. Quantitative data used in the preparation of the map were restricted to vitrinite-reflectance and Conodont Color Alteration Index analyses because these types of data are the most common and besi Alteration Index analyses because these types of data are the most common and best quantifiable thermal-maturity data available in Alaska. The database behind this map (Johnsson and others, 1992), consists of 3,716 vitrinite-reflectance determinations from 2,123 outcrop localities, 14,474 Conodont Color Alteration Index determinations from 1,306 outcrop localities, and 4,482 vitrinite-reflectance determinations from 12 wells. Where vitrinite-reflectance or Conodont Color Alteration Index data were sparse or unavailable, other organic and inorganic thermal-maturity data from the literature cited below were used to help constrain thermal-maturity. Such data include: rock-vealuation pyrolysis ( $T_{max}$ ), thermal-alteration index (TAI), fluid inclusion, illite crystallinity, zeolite mineralogy, and fission-refe data. In ancircular, the laumonite-problemic-numerblive forcing of Durat fission-track data. In particular, the laumontite-prehnite-pumpellyite facies of Duse Bacon (1994) generally correlates with the supermature thermal-maturity unit defined b te-reflectance and Conodont Color Alteration Index data, and Dusel-Bacon (1994) wa lingly used to constrain the supermature thermal-maturity map unit in places. The geologic base (metamorphic, plutonic, and unmetamorphosed bedrock, surfici nits, and faults) is modified from Dusel-Bacon (1994) and Beikman (1980).

 umits, and Hauts) is modified from Dister-Pacton (1994) and betKinal (1980).
 Bayliss, G.S., and Magoon, L.B., 1988, Organic facies and thermal maturity of sedimentary rocks in the National Petroleum Reserve in Alaska, *in Gryc, G., ed., Geology and exploration of the* National Petroleum Reserve in Alaska, *in Gryc, G., ed., Geology and exploration of the* National Petroleum Reserve in Alaska, *in Status, Parkov, Status, Status, In Ruo, P.D., ed., Focus on* Alaska's Coal' 86, Proceedings of the Condernee held A Anchorage Alaska October 27–30, 1986; Fairbanks, Alaska, Mineral Industry Research Laboratory, p. 300–335.
 Beitkman, H.M., 1980, Geologic map of Alaska: U.S. Geological Survey, 1:2,500,000, 2 sheets.
 Bird, K.J., 1987, The framework geology of the North Slope of Alaska as related to oil-source rock correlations, *in Tailueux*, *1*, and Weinner, P., Alaskan North Slope geology: Bakerfield, California, and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 121–143.
 Bird, K.J., and Magoon, L.B., 1987, Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska: U.S. Geological Survey Bulletin 1778, 329 p.
 Broøge, W.-P., Reiser, H.N., Dutro, J.T., *In*, and Detterman, R.L., 1981, Organic geochemical data for Brosgé, W.P., Reiser, H.N., Dutro, J.T., Jr., and Detterman, R.L., 1981, Organic geochemical data f Mesozoic and Paleozoic shales, central and eastern Brooks Range, Alaska: U.S. Geologic Control and Control Bruns, T.R., von Huene, R., Curlotta, R.C., Lewis, S.D., 1985, Summary geologic report for th Shumagin Outer Continental Shelf (OCS) Planning Area, Alaska: U.S. Geological Survey Open Shumagin Outer Continental Shelf (OCS) Planning Area, Alaska: U.S. Geotogicai survey open File Report 85–32, 58 p. neron, A.R., Norris, D.K., and Pratt, K.C., 1986, Rank and other compositional data on coals an B: Geological Survey of Canada, p. 665-670. 2. JONGPUM VALVEY OF CARAVA, p. 003-070. Zlaypool, G.E., and Magoon, L.B., 1988, Oil and gas source rocks in the National Petroleum Reserve in Alaska, in Grey, G., ed., Geology and exploration of the National Petroleum Reserve in Alaska 1974 to 1982, p. 451-481.

1974 to 1982, p. 431–481. Dusel-Bacon, C., 1994, Metamorphic history of Alaska, *in Plafker*, G., and Berg, H.C., eds., The geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, v. Gl. plate, 41: 5200,000, 2 sheets.
Fisher, M.A., 1982, Petroleum geology of Norton Basin, Alaska: American Association of Petroleum Geologists Bulletin, v. 66, p. 288–301.
Fisher, M.A., and Magoon, L.B., 1978, Geologic framework of Lower Cook Ialet, Alaska: American Association of Durchoum Geologists Rolling vs. 62, p. 232. troleum Geologists Bulletin, v. 62, p. 373-402. Gautier, D.L., Bird, K.J., and Colten-Bradley, V.A., 1987, Relationship of clay mineralogy, thermal maturity, and geopressure in wells of the Point Thomson area, *in Bird*, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska: U.S. Geological Survey Bulletin 1778, p. 199-207.

 Alaska: U.S. Geological Survey Bulletin 1778, p. 199–207.
 Gryc, G., dittor, 1988, Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982: U.S. Geological Survey Pordessional Paper 1399, 940 p.
 Harris, A.G., Ellensicek, L.F., Mayfield, C.F., and Tailler, L.L., 1983. Thermal maturation values (consolut color alteration indices) for Paleozoic and Triassic rocks, Chandler Lake, De Long Mountains, Howard Pass, Killik River, Wisheguk Mountain, and Point Hope quadrangles, northwest Alaska, and subsurface NPRA: U.S. Geological Survey Open-File Report 83-505. 15 p.
 Harris, A.G., Lane, H.R., Tailler, I.L., and Ellerisck, I., 1987, Condont thermal maturation patterns in Phetozoic and Triassic rocks, northwest A.G. Godogica and exploration implications, *in* Failleur, I., and Weimer, P., Alaskan North Slope geology: Bakersfield, Cal Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mine

Alaska Geological Society, p. 181–191.
Howell, D.G., Johnsson, M.J., Underwood, M.B., Lu Huafu, and Hillhouse, J.W., 1992, Tectoni Carl, D.G., Joinsson, M.J., Underwood, arC.J. La Thatti, and finitoux, J.W. 1922. Texton evolution of the Kandik region, east-central Alaska: Preliminary interpretations, in Bradley, D.C. and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1990; U.S. Geological Survey Bulletin 1999, p. 127–140. vell, D.G., Bird, K.J., Lu Huafu, and Johnsson, M.J., 1992, Tectonics and petroleum potential the Brooks Range fold and thrust belt—A progress report, *in* Bradley, D.C., and Ford, A.B., eds. Geologic studies in Alaska by the U.S. Geological Survey during 1990: U.S. Geological Survey 3ulletin 1999, p. 112–126.

asson, M.J., Pawlewicz, M.J., Harris, A.G., and Valin, Z.C., 1992, Vitrinite reflectance as conodont color alteration index data from Alaska: Data to accompany the thermal maturity map c Alaska: U.S. Geological Survey Open-File Report 92-409, 3 diskettes. ghland, M.M., Underwood, M.B., and Wiley, T.J., 1990, Thermal maturity, tectonostratigraphi terranes, and regional tectoric history: An example from the Kandik area, east-central Alaska, i Nuccio, V.F., and Barker, C.E., eds., Applications of thermal maturity studies to energe exploration: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists,

Jagoon J. B. and Bird K.J. 1988 Evaluation of petroleum source rocks in the National Petrol Reserve in Alaska, using organic-carbon content, hydrocarbon content, visual kerogen, an vitrinite reflectance, in Gryc, G., ed., Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982, p. 381–450.

coon, L.B., and Claypool, G.E., 1981, Petroleum geology of the Cook Inlet Basin—An exploratio model: American Association of Petroleum Geologists Bulletin, v. 65, p. 1,043–1,061. maturity, richness, and type of organic matter of source rock units, in Bird, N.J., and Magoon, I.B., eds., Pertoleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska: U.S. Geological Survey Bulletin 1778, p. 127–179.
Lean, H., 1977, Organic geochemistry, lithology, and paleontology of Feit Report 77–813, 63 p.

erritt, R.D., 1985a, Coal atlas of the Matanuska Valley, Alaska: Alaska Department of Natur Resources, Division of Geological and Geophysical Surveys Public Data File 85-45, 270 p. –1985b, Coal atlas of the Nenana Basin, Alaska: Alaska Department of Natural Resources. Jivision of Geological and Geophysical Surveys Public Data File 85–41, 197 p. –1986a, Geology and coal resources of the Wood River Field, Nenana Basin: Alaska Department of Autural Resources. Division of Geological and Geophysical Surveys Public Data File 86–68, 11 p.

Drivision of Geological and Geophysical Surveys Report of Investigations 90-1, 181 p. Ros, P.D., 1980, Petrographic, mineralogical, and chemical characterization of certain Arctic Alaska coals from the Cape Beaufort region: Alaska Department of Natural Resources, Drivision of Geological and Geophysical Surveys, Mineral Industry Research Laboratory Report No. 44, 66 P. Rao, P.D., and Smith, J.E., 1983. Petrology of Createcous coals from northern Alaska: Alask Department of Natural Resources, Division of Geological and Geophysical Surveys, Minera Industry Research Laboratory Report No. 64, 141 p. Introducty research automatic reference of the second s

in press, Gilead sandstone, northeastern Brooks Range, Alaska: An Albian to Cenomania — in pices, official sandstore, induction in brokes many, Anakar, An Fuldari to Cenominani or marine clastic succession, in Reger, R., ed., Short Notes on Alaskan Geology, Alaska Division of Geological and Geophysical Surveys Professional Report 111. binson, M.S., 1989, Kerogen microscopy of coal and shales from the North Slope of Alaska: Alaska Division of Geological and Geophysical Surveys Public Data File 89-22, 19 p. Drisson in Ceongran and Ceongrand a during's funne Data in Colorada (1977) Smith, J., and Rao, P.D., 1986, Geology and coal resources of the Bering River Coal Field, in Rac P.D., ed., Focus on Alaska's Coal '86, Proceedings of the Conference held at Anchorage Alask October 27–30, 1986; Fairbanks, Alaska, Mineral Industry Research Laboratory, p. 266–299.

Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p 104-107. 8, Hydrocarbon source potential and thermal maturity of the Sanctuary Formation (Midd ne), northern foothills of the Alaska Range, in Galloway, J.P., and Hamilton, T.D., ed Geologic Studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological

Circular 1016, p. 117-120. ley, R.G., McLean, H., and Pawlewicz, M.J., 1990, Petroleum source potential and therm in the state of the .P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological urvey Bulletin 1946, p. 65–76. Survey Bulletin 1946, p. 65-76.
derwood, M.B., Laughland, M.M., Wiley, T.J., and Howell, D.G., 1989, Thermal maturity an organic geochemistry of the Kandik basin region, east-central Alaska: U.S. Geological Surve Open-File Report 89-353, 41 p.

Inderwood, M.B., Brocculeri, T., Bergfeld, D., Howell, D.G., and Pawlewicz, M., 1992, Statistica

# PRINCIPAL CONTRIBUTORS Kenneth J. Bird, Cynthia Dusel-Bacon, Christopher F. Hamilton, Anita G. Harris, Leslie B. Magoon,

Mark J. Pawlewicz, and Zenon C. Valin

# lished data and samples contributed by

K.E. Auanis
T.S. Ahlbrandt
American Oil Co.
A. Anderson
H.C. Berg
R.B. Blodgett
D.A. Bodnar
D. Bohn
S. Boundy-Sanders
S.E. Box
E.E. Brabb
D.A. Brew
British Petroleum
W.P. Brosgé
T.K. Bundtzen
C. Carlson
R.M. Chapman
Chevron Oil Co.
M. Churkin, Jr.
K.H. Clautice
J.G. Clough
H.A. Cohen
H.E. Cook
S.M. Curtis

J.T. Dillon J.H. Dover J.A. Dumoulin J.T. Dutro, Jr. I.F. Ellersieck P. Folger H.L. Foster W.G. Gilbert P.D. Gruzlovic P.D. Gruziovic G. Hakkila C.L. Hanks P.J. Haeussler B.K. Holdsworth A.C. Huffman, Jr. D.L. Jones S.M. Karl J.S. Kelley M.M. Luuphland M.M. Laughland C.F. Mayfield M.L. Miller C.M. Molenaar T.E. Moore C.G. Mull

M.W. Mullen

J.M. Murphy S.W. Nelson W.J. Nokleberg A.T. Ovenshine W.W. Patton, Jr. G. Plafker A.W. Potter R.R. Reifenstuhl H.N. Reiser S.B. Roberts J.M. Schmidt Shell Oil Co. N.J. Silberling J.P. Siok R.G. Stanley I.L. Tailleur W. Thompson A.B. Till M.B. Underwood K.F. Watts F.R. Weber T.J. Wiley

### Return to Main Menu