ox Elder County, Utah, and
k, and Albion Ranges), where
strong, 1968a; Compton and
Idaho (Pioneer Mountains),
o medium grade (Dover and
quop Mountains, Wood Hills,
ks are metamorphosed and
outheastern San Bernardino
ork, Old Woman, Maria, and
ome Mesozoic rocks are
1979).

ION

in which to assess thermal
Original burial metamorphic
by post-Triassic sedimentary
mal events related to igneous
ermal patterns for the systems
partly because conodonts are
vide an invaluable tool for
mplex geologic areas.
bon and mineral exploration
assessments. The thermal
to the thermal window for
on and the thermal cutoff for
mal maturity can be related to
ingly larger, and areas of low
each older geologic system.
be geographically coincident
y to overthrust belts. Near the
emely complex. For example,
erts Mountains thrust system,
s have been thrust eastward
cks. In other areas in central
d Desborough, 1979). Later
oduce a complex mosaic of
ame is true of Silurian and
les occur in other areas.
7°30' W. longitude and most
N. latitude and west of 113°
so occur in all Paleozoic rocks
ese high values north of the
extensive Mesozoic through
of high thermal maturity in
orthern Utah County, Utah,
h basin. Our CAI data suggest
argets for hydrocarbon
t-central Nevada and Millard
alues. The same is true for
f low CAI values is greater for
rocarbon exploration targets.
n Nevada, the Eagle Springs
arbons are in Tertiary welded
ch may have a multiple origin
Claypool and others, 1979:

STEM

e order in which they were
tion of the CAI map for any
the composite effect of the
gic system as well as younger

ur interpretations apply to the
intervening basins. In the area
composed chiefly of Archean
sic igneous rocks that intrude
ual CAI map is enhanced by a
s and should be made with
oic Erathem and the Triassic
lan CAI map requires data on
Devonian depositional and

YSTEM

have low CAI values, chiefly
are generally associated with
AI values in the vicinity of the
These mountains are cored by
nd on the CAI maps for the
rea of moderate to high CAI
rge igneous intrusions of the
land Range, Gold Hill Mining
ar the northern Utah-Nevada
reviously in Permian rocks by
a of moderate CAI values in
anitic pluton in central eastern

as immediately southeast of it
lly greater than 4. In this area,
leposits.

YSTEM

ah, and the eastern thrust belt
ally have CAI values of 2.5 or
CAI values that are related to
AI areas in west Tooele and
County, Nevada, which also
ystem. The very large area of
e County, Nevada, coincides
Permian through Triassic time
e Ely basin. The thickness of
is still within the range for low

lt Lake, Wasatch, and Utah
basin which contains 5,000 to
in Cassia County, Idaho, and
o a north-trending Permian
sin. In this area, the moderate
obably related to thick Lower
n western Cassia County and
noderate thicknesses of both
roduce a thick total Permian

east Elko County, Nevada,
ough (Stevens, 1977) and the
w and Collinson, 1978). This
ntains at least 6,000 feet of

Permian rock as well as 1,000 or more feet of overlying Triassic.

A large area of very high CAI values in western Nevada lies chiefly west of the leading edge of the Golconda thrust and is probably linked to the thick eugeosynclinal deposits of the overlying Triassic System. In Humboldt and Pershing Counties, moreover, in the northern part of this CAI high, the Permian also contains thick eugeosynclinal accumulations. Still another area of high CAI values lies north of the Snake River Plain in Custer County, Idaho. At present, little is known about the Permian sequence in this area. However, this is an area of Mesozoic through Quaternary igneous activity and the high CAI values could be easily related to high heat flow.

CAI MAP OF THE PENNSYLVANIAN SYSTEM

The east-central Nevada area continues to have low to moderate CAI values in Pennsylvanian rocks. This is because the Pennsylvanian (McKee and others, 1975) as well as overlying younger systems are thin in this area. The area of moderate CAI values in northeast White Pine County, Nevada, and western Juab County, Utah, is unrelated to Pennsylvanian depositional patterns but does reflect the thick younger overburden as well as younger igneous activity.

The thermal high in parts of Wasatch, Utah, Juab, and Tooele Counties, Utah, on this and the CAI maps of older Paleozoic systems corresponds to thick accumulations of Pennsylvanian and Permian rocks in the Oquirrh basin (McKee and others, 1975). Similarly, moderate CAI values are associated with moderately thick Pennsylvanian and Permian deposits in the Paradox basin of east-central Utah and western Colorado. Low CAI values characterize the Pennsylvanian rocks bordering the Uinta uplift in Daggett, Duchesne, Summit, and Uintah Counties, Utah.

In the vicinity of the Las Vegas fault, Pennsylvanian CAI values are high as are CAI values in older Paleozoic rocks in this same area. This high does not appear to be related to overburden, which is relatively thin in this area.

Relatively thin shallow-water marine Pennsylvanian deposits that overlap the Roberts Mountains thrust system have low CAI values whereas most eugeosynclinal Pennsylvanian deposits west of the Golconda thrust system have very high values. The high CAI values in northern Elko County north of the Wells fault may represent eastward transport of this same eugeosynclinal sequence.

The high CAI values in Cassia County, Idaho, continue to reflect the thick Pennsylvanian and Permian accumulations of the Sublette basin and are near the Raft River area of post-Triassic metamorphism (Compton and others, 1977). The CAI high in Custer and Blaine Counties, Idaho, is probably the result of high heat flow and moderate to possibly thick Pennsylvanian and Permian overburden as well as thick accumulations of Mesozoic and Cenozoic volcanic rocks.

CAI MAP OF THE MISSISSIPPIAN SYSTEM

East-central Nevada, western Millard County and the Uinta uplift area, Utah, and the overthrust belt of southeastern Idaho and northeasternmost Utah contain the major areas of low to moderate CAI values. The largest area of moderate to low CAI values (moderate on the west and low on the east) is centered at the common border of Eureka, Nye, and White Pine Counties, Nevada. In this area, the eastward decrease in CAI mimics the Mississippian isopach trend (Poole and Sandberg, 1977, figs. 4 and 6). The return to moderate CAI values in eastern White Pine County is probably related to heat flow associated with the igneous intrusions in the Kern Mountains and adjacent areas. The CAI trend in western Millard County, Utah, apparently correlates with Mississippian as well as younger overburden trends.

The only two oil fields in Nevada are in Railroad Valley (northeastern Nye County) and within a large area of low CAI. The ranges bordering Railroad Valley contain some Paleozoic rocks that are at peak thermal levels for hydrocarbon generation (Poole and others, 1979). According to Claypool and others (1979), oil in the Trap Spring field had a Chainman Shale source (Mississippian) whereas oil in the Eagle Springs field probably had a Sheep Pass Formation source (Paleocene). Other workers (Poole and others, 1979) have suggested that the Chainman is the major source of the oil in Railroad Valley.

The high CAI values in eastern Tooele, Utah, and Wasatch Counties, Utah, conform to the superposition of Mississippian, Pennsylvanian, and Permian depocenters in that area. High CAI values in Custer and Butte Counties, Idaho, likewise conform to high overburden values related to a thick northwest-trending accumulation of Mississippian and younger Paleozoic deposits.

CAI MAP OF THE DEVONIAN SYSTEM

This map shows a major decrease in the area of low CAI values compared to the maps for younger systems. The areas of high CAI values are more extensive than but in the same general vicinity as those on the map for the Mississippian System. The thermally complex area between the Golconda thrust system and the leading edge of the Roberts Mountains thrust system represents the composite effects of different thermal levels in klippen, windows, and sheets within an imbricate thrust system as well as thermal highs related to post-Paleozoic igneous activity. East of the leading edge of the Roberts Mountains thrust system, in east-central Nevada and Millard County, Utah, Devonian rocks have low to moderate CAI values which reflect Devonian and younger isopach trends.

CAI MAP OF THE SILURIAN SYSTEM

We have the least number of data points for the Silurian System. In general the Silurian rocks we have sampled have high CAI values. Low to moderate CAI values occur immediately west of and at the leading edge of the Roberts Mountains thrust system in central Nevada and near the central Utah-Nevada border area. As in overlying systems, a CAI high associated with igneous activity occurs along the northern Utah-Nevada border area, mainly the western Tooele County, Utah.

CAI MAP OF THE ORDOVICIAN SYSTEM

Most Ordovician rocks have high CAI values that are related to the composite effects of Ordovician and younger depositional patterns as well as tectonic burial and igneous activity.

Ordovician rocks have moderate CAI values near the center of the Ordovician Ibex basin in Millard County, Utah, and southeast White Pine County, Nevada. This depocenter also overlaps the area of relatively thicker Silurian and Devonian deposition.

The same complex pattern of thermal values associated with the leading edge of the Roberts Mountains thrust system in Eureka, north-central Nye, and western Elko Counties, Nevada, seen on the Devonian CAI map persists on the Ordovician CAI map for the same reasons.

In the overthrust belt of southeast Idaho and northeasternmost Utah, Ordovician rocks have CAI values of 2 to 3½ and are well within peak levels of gas production. In general, stratigraphically higher Paleozoic and Triassic sequences in this area are at the same or lower thermal levels.

Ordovician rocks present fewer target areas for hydrocarbon exploration than Devonian and younger rocks.

ACKNOWLEDGMENTS

Most of the data points are from U.S. Geological Survey conodont collections. We gratefully acknowledge the cooperation of conodont workers and their institutions or companies across the United States who permitted us to index their conodont collections from the Great Basin. We particularly wish to thank specifically those whose large collections contributed substantially to the data base: F. H. Behnken, Augustana College, Rock Island, Ill.; D. L. Clark, Univ. Wisconsin; J. W. Collinson, Ohio State Univ.; R. L. Ethington, Univ. Missouri; Gilbert Klapper, Univ. Iowa; H. R. Lane and J. F. Basemann, Amoco Research Center, Tulsa, Okla.; J. F. Miller, Southwest Missouri Univ.; L. C. Mosher, Phillips Research Center, Bartlesville, Okla.; M. A. Murphy, Univ. California, Riverside.

Thanks are due M. P. Hunt, E. F. MacDonald, L. E. Savoy, and L. J. Vigil for their assistance in sample processing, indexing, map compilation, and drafting and for withstanding the harassment that accompanies the rapid accumulation of data.

The report was reviewed by K. A. Howard, K. B. Ketner, F. G. Poole, and M. E. Taylor. We appreciate their speed, thoroughness, and criticisms. Special thanks are due F. G. Poole for his contribution on regional structure and K. A. Howard for his contribution on regionally metamorphosed Paleozoic rocks; both their contributions are included in the text.

REFERENCES CITED

Armstrong, R. L., 1968a, Mantled gneiss domes in the Albion Range, southern Idaho: Geol. Soc. America Bull., v. 79, p. 1295–1314.

_____ 1968b, Sevier orogenic belt in Nevada and Utah: Geol. Soc. America Bull., v. 79, p. 429–458.

Armstrong, R. L., and Hansen, Edward, 1966, Cordilleran infrastructure in the eastern Great Basin: Am. Jour. Sci., v. 264, p. 112–127.

Claypool, G. E., Fouch, T. D., and Poole, F. G., 1979, Chemical correlation of oils and source rocks in Railroad Valley, Nevada: Geol. Soc. America Abs. with Programs, v. 11, no. 7, p. 403.

Compton, R. R., Todd, V. R., Zartman, R. E., and Naeser, C. W., 1977, Oligocene and Miocene metamorphism, folding, and low-angle faulting in northwestern Utah: Geol. Soc. America Bull., v. 88, p. 1237–1250.

Crittenden, M. D., Jr., 1959, Mississippian stratigraphy of the central Wasatch and western Uinta Mountains, Utah, *in* Intermountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf.: p. 63–74.

_____ 1961, Magnitude of thrust faulting in northern Utah: U.S. Geol. Survey Prof. Paper 424–D, p. D128–D131.

Crittenden, M. D., Jr., Coney, P. J., and Davis, George, 1978, Tectonic significance of metamorphic core complexes in the North American Cordillera: Geology, v. 6, p. 79–80.

Dover, J. H., and others, 1976, Geologic map of the Pioneer Mountains region, Blaine and Custer Counties, Idaho: U.S. Geol. Survey Open-file Rept. 76–75.

Ekren, E. B., Buckman, R. C., Carr, W. J., Dixon, G. L., and Quinlivan, W. D., 1976, East-trending structural lineaments in central Nevada: U.S. Geol. Survey Prof. Paper 986, 16 p.

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration—an index to organic metamorphism: U.S. Geol. Survey Prof. Paper 995, 27 p.

French, D. E., and Freeman, K. J., 1979, Volcanics yield another oil field: World Oil, May, p. 58–63.

Hamilton, W. B., 1964, Nappes in southeastern California [abs.]: Geol. Soc. America Spec. Paper 76, p. 274.

Harris, A. G., Harris, L. D., and Epstein, J. B., 1978, Oil and gas data from Paleozoic rocks in the Appalachian basin: maps for assessing hydrocarbon potential and thermal maturity (conodont color alteration isograds and overburden isopachs): U.S. Geol. Survey Misc. Geol. Inv. Map I–917–E, 4 sheets, scale 1:2,500,000.

Howard, K. A., 1971, Paleozoic metasediments in the northern Ruby Mountains, Nevada: Geol. Soc. America Bull.,v. 82, p. 259–264.

King, P. B., and Beikman, H. M., 1974, Geologic map of the United States: Reston, Va., U.S. Geological Survey, 3 sheets, scale 1:2,500,000.

McKee, E. D., Crosby, E. J., and others, 1975, Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Prof. Paper 853, pt. 3, 17 pls.

McKee, E. D., and others, 1959, Paleotectonic maps of the Triassic System: U.S. Geological Survey Misc. Geol. Inv. Map I–300.

Petroleum Information Corp., 1978, Oil and Gas map of the United States including basins, uplifts and basement rocks: Denver, Colo., scale 1:3,500,000.

Poole, F. G., Baars, D. L., Drewes, H. D., Hayes, P. T., Ketner, K. B., McKee, E. D., Teichert, C., and Williams, J. S., 1967, Devonian of the southwestern United States, *in* Oswald, D. H., ed., International Symposium on the Devonian System, v. 1: Alberta Society of Petroleum Geologists, Calgary, p. 879–912.

Poole, F. G., and Desborough, G. A., 1979, Oil and metals in Ordovician and Devonian kerogenous marine strata of central Nevada [abs.]: Am. Assoc. Petroleum Geologists Bull., (in press).

Poole, F. G., Fouch, T. D., and Claypool, G. E., 1979, Evidence for two major cycles of petroleum generation in Mississippian Chainman Shale of east-central Nevada [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 63, no. 5, p. 838.

Poole, F. G., and Sandberg, C. A., 1977, Mississippian paleogeography and tectonics of the Western United States, *in* Stewart, J. H., and others, eds., Paleozoic paleogeography of the Western United States: Pacific Coast paleogeography symposium 1: Los Angeles, Calif., Pacific Section Society of Economic Paleontologists and Mineralogists, p. 67–85.

Poole, F. G., Sandberg, C. A., and Boucot, A. J., 1977, Silurian and Devonian paleogeography of the Western United States, *in* Stewart, J. H., and others, eds., Paleozoic paleogeography of the Western United States: Pacific Coast paleogeography symposium 1: Los Angeles, Calif., Pacific Section Society Economic Paleontologists and Mineralogists, p. 39–65.

Powers, R. B., 1977, Assessment of oil and gas resources in the Idaho-Wyoming thrust belt, *in* Heisey, E. L., and Lawson, D. E., eds.,Rocky Mountains thrust belt, geology and resources, Wyoming Geol. Assoc. 29th Ann. Field Conf.: Casper, Wyo., Wyoming Geol. Assoc., p. 629–637.

Ross, R. J., Jr., 1977, Ordovician paleogeography of the Western United States, *in* Stewart, J. H., and others, eds., Paleozoic paleogeography of the Western United States: Pacific Coast paleogeography symposium 1: Los Angeles, Calif., Pacific Section Society of Economic Paleontologists and Mineralogists, p. 19–38.

Speed, R. C., 1979, Collided Paleozoic microplate in the Western United States: Jour. of Geology, v. 87, p. 279–292.

Stevens, C. H., 1977, Permian depositional provinces and tectonics, Western United States, *in* Stewart, J. H., and others, eds., Paleozoic paleogeography of the Western United States: Pacific Coast paleogeography symposium 1: Los Angeles, Calif., Pacific Section Society of Economic Paleontologists and Mineralogists, p. 113–135.

Stewart, J. H., Albers, J. P., and Poole, F. G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: Geol. Soc. of America Bull., v. 79, no. 10, p. 1407–1413.

Stone, Paul, and Howard, K. A., 1979, Paleozoic metasedimentary rocks in the eastern Mojave Desert, California: Geol. Soc. America Abstracts with Programs, v. 11, no. 3, p. 130.

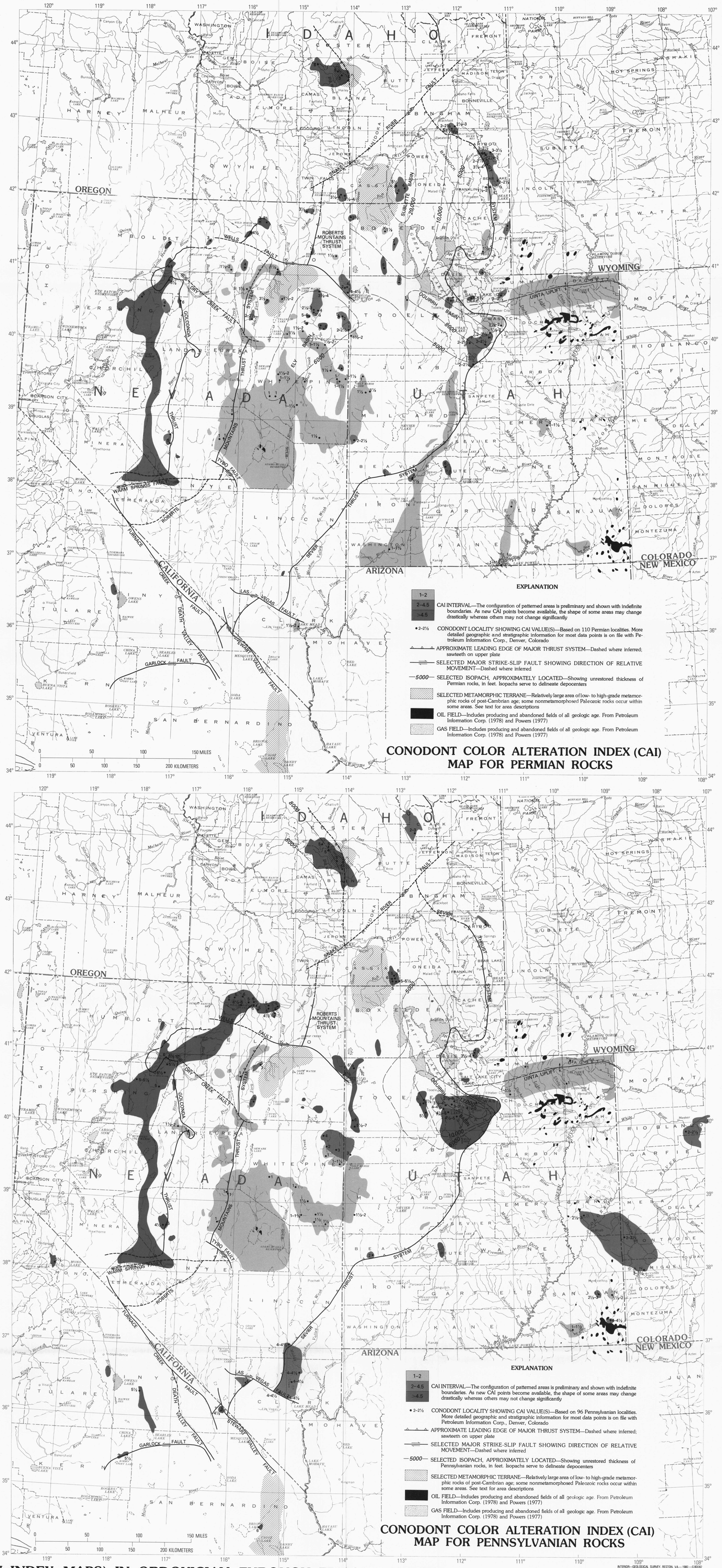
Thorman, C. H., 1970, Metamorphosed and nonmetamorphosed Paleozoic rocks in the Wood Hills and Pequop Mountains, northeast Nevada: Geol. Soc. America Bull., v. 81, no. 8, p. 2417–2447.

Thorman, C. H., and Ketner, K. B., 1979, West-northwest strike-slip faults and other structures in allochthonous rocks in central and eastern Nevada and western Utah, in Newman, G., ed., Great Basin guidebook: Denver, Colo., Rocky Mountain Association of Geologists , p. 123–1340

Wardlaw, B. R., and Collinson, J. W., 1978, Stratigraphic relations of the Park City Group (Permian) in eastern Nevada and western Utah: American Association Petroleum Geologists Bull., v. 62, p. 1171–1184.

Wardlaw, B. R., Collinson, J. W., and Ketner, K. B., 1979, Regional relations of middle Permian rocks in Idaho, Nevada, and Utah, in Newman, G., ed., Great Basin guidebook: Denver, Colo., Rocky Mountain Association of Geologists, p. 277–284.

[1]Getty Oil Company, Exploration and Production Research Center, Houston, Texas
[2]Dept. Geology, College of Charleston, Charleston, S. C.



EXPLANATION

1–2 / 2–4.5 / >4.5 — CAI INTERVAL—The configuration of patterned areas is preliminary and shown with indefinite boundaries. As new CAI points become available, the shape of some areas may change drastically whereas others may not change significantly

•2–2½ — CONODONT LOCALITY SHOWING CAI VALUE(S)—Based on 110 Permian localities. More detailed geographic and stratigraphic information for most data points is on file with Petroleum Information Corp., Denver, Colorado

APPROXIMATE LEADING EDGE OF MAJOR THRUST SYSTEM—Dashed where inferred; sawteeth on upper plate

SELECTED MAJOR STRIKE-SLIP FAULT SHOWING DIRECTION OF RELATIVE MOVEMENT—Dashed where inferred

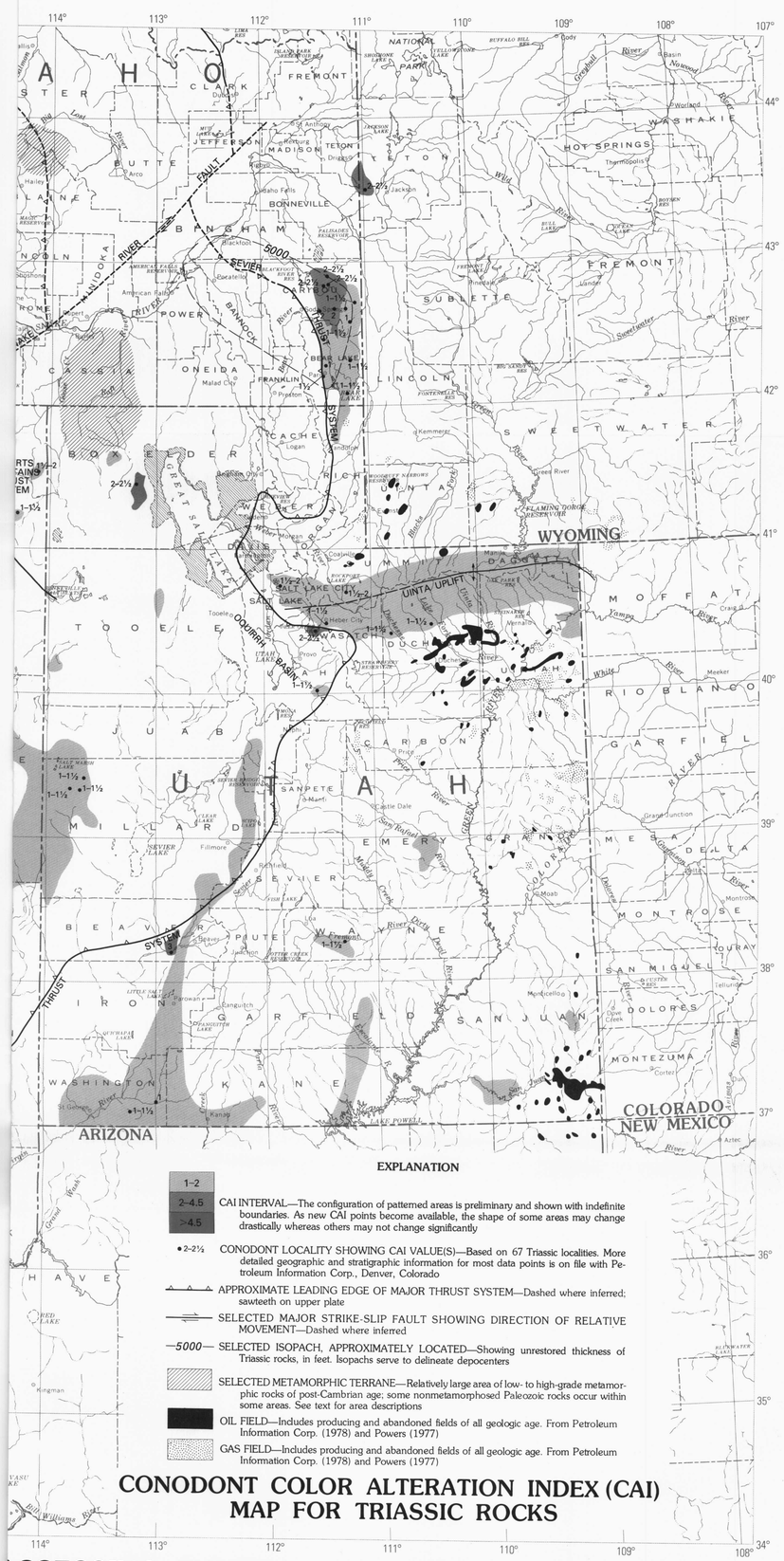
—5000— SELECTED ISOPACH, APPROXIMATELY LOCATED—Showing unrestored thickness of Permian rocks, in feet. Isopachs serve to delineate depocenters

SELECTED METAMORPHIC TERRANE—Relatively large area of low- to high-grade metamorphic rocks of post-Cambrian age; some nonmetamorphosed Paleozoic rocks occur within some areas. See text for area descriptions

OIL FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

GAS FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

CONODONT COLOR ALTERATION INDEX (CAI) MAP FOR PERMIAN ROCKS



EXPLANATION

1–2 / 2–4.5 / >4.5 — CAI INTERVAL—The configuration of patterned areas is preliminary and shown with indefinite boundaries. As new CAI points become available, the shape of some areas may change drastically whereas others may not change significantly

•2–2½ — CONODONT LOCALITY SHOWING CAI VALUE(S)—Based on 67 Triassic localities. More detailed geographic and stratigraphic information for most data points is on file with Petroleum Information Corp., Denver, Colorado

APPROXIMATE LEADING EDGE OF MAJOR THRUST SYSTEM—Dashed where inferred; sawteeth on upper plate

SELECTED MAJOR STRIKE-SLIP FAULT SHOWING DIRECTION OF RELATIVE MOVEMENT—Dashed where inferred

—5000— SELECTED ISOPACH, APPROXIMATELY LOCATED—Showing unrestored thickness of Triassic rocks, in feet. Isopachs serve to delineate depocenters

SELECTED METAMORPHIC TERRANE—Relatively large area of low- to high-grade metamorphic rocks of post-Cambrian age; some nonmetamorphosed Paleozoic rocks occur within some areas. See text for area descriptions

OIL FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

GAS FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

CONODONT COLOR ALTERATION INDEX (CAI) MAP FOR TRIASSIC ROCKS

EXPLANATION

1–2 / 2–4.5 / >4.5 — CAI INTERVAL—The configuration of patterned areas is preliminary and shown with indefinite boundaries. As new CAI points become available, the shape of some areas may change drastically whereas others may not change significantly

•2–2½ — CONODONT LOCALITY SHOWING CAI VALUE(S)—Based on 96 Pennsylvanian localities. More detailed geographic and stratigraphic information for most data points is on file with Petroleum Information Corp., Denver, Colorado

APPROXIMATE LEADING EDGE OF MAJOR THRUST SYSTEM—Dashed where inferred; sawteeth on upper plate

SELECTED MAJOR STRIKE-SLIP FAULT SHOWING DIRECTION OF RELATIVE MOVEMENT—Dashed where inferred

—5000— SELECTED ISOPACH, APPROXIMATELY LOCATED—Showing unrestored thickness of Pennsylvanian rocks, in feet. Isopachs serve to delineate depocenters

SELECTED METAMORPHIC TERRANE—Relatively large area of low- to high-grade metamorphic rocks of post-Cambrian age; some nonmetamorphosed Paleozoic rocks occur within some areas. See text for area descriptions

OIL FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

GAS FIELD—Includes producing and abandoned fields of all geologic age. From Petroleum Information Corp. (1978) and Powers (1977)

CONODONT COLOR ALTERATION INDEX (CAI) MAP FOR PENNSYLVANIAN ROCKS

ASSESSING THERMAL MATURITY (CONODONT COLOR ALTERATION INDEX MAPS) IN ORDOVICIAN THROUGH TRIASSIC ROCKS IN NEVADA AND UTAH AND ADJACENT PARTS OF IDAHO AND CALIFORNIA

By
Anita G. Harris, Bruce R. Wardlaw, Claude C. Rust[1], and Glen K. Merrill[2]

1980

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1980—G80082

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225

D-01A