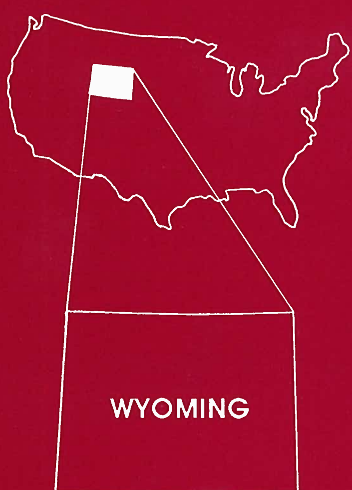
WYOMING GEOMAPS

by
Sheila Roberts



Geological Survey of Wyoming
Gary B. Glass, State Geologist
Laramie, Wyoming

Educational Series 1
1989

First printing of 3,000 copies by Pioneer Printing, Cheyenne, Wyoming.

This and other publications available from: The Geological Survey of Wyoming
P.O. Box 3008, University Station
Laramie, Wyoming 82071
(307) 766-2286

FRONT COVER: Space-eye view of Wyoming, a LANDSAT photograph. The photo is a composite of many smaller pictures taken from 570 miles above the Earth's surface by an unmanned, Earth-orbiting NASA satellite. The colors are not true visible colors: vegetation shows up as bright red patches, especially noticeable in and around mountains and near rivers; water bodies like Yellowstone Lake (in the northwest corner of the map) and numerous other lakes and reservoirs are black; basins and low-lying areas are mostly shades of yellow, gray, green, and light brown; mountains and upland areas tend to darker browns and some have white snow. A few of the white spots are clouds; for example, there are white clouds and their dark shadows on the east side of the Bighorn Mountains. Photographic images like these and more detailed close-up aerial views have revolutionized geologic mapping and our understanding of the planet. (Map compiled by the U.S. Department of Agriculture Aerial Photograph Field Office; color separations courtesy of the Department of Geology and Geophysics, University of Wyoming, Laramie.)

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PREFACE AND ACKNOWLEDGMENTS

PREFACE

People have been studying and mapping the geology of Wyoming since the Hayden Surveys of the 19th Century. The State is a mapper's paradise — so much beautifully exposed rock. This book offers an introduction to some of the aspects of the State's geology that can be described effectively with maps. *Wyoming geomaps* is unique in providing introductory graphic information on such a wide variety of Wyoming geology (and related) topics.

This book initiates a new line of publications from the Geological Survey of Wyoming, the Educational Series. A separate pamphlet of classroom activities, to be used with the maps, is available free of charge to residents in Wyoming with purchase of *Wyoming Geomaps* and for a small charge to addresses outside Wyoming.

ACKNOWLEDGMENTS

Don Steeples and Rex Buchannan of the Kansas Geological Survey started this. It was their publication, *Kansas geomaps*, that provided the inspiration and model for *Wyoming geomaps*. Thanks for a great idea!

I was very fortunate to have reviewers who offered support, direction, and correction from their various fields of expertise. The list is long: D.L. Blackstone, Jr. (structural geology, Precambrian basement), Brent Breithaupt (paleontology), Jim Case (earthquakes and active faults), Rodney DeBruin (oil and gas), Gary Glass (coal, and review of the entire manuscript), Ray Harris (industrial minerals, construction materials, and uranium; museums), Dan Hausel (metals, precious stones, and semiprecious stones; museums), Henry Heasler (geothermal), Richard Jones (coal; museums), Dennis Knight (vegetation), J. David Love (geologic map and review of much of the manuscript), Brainerd Mears, Jr. (Pleistocene), Larry Munn (soils), Lawrence M. Ostresh, Jr. (topographic map), Michelle Potkin (vegetation), Peter Shive (magnetics), Scott Smithson (gravity), Arthur Snoke (structural geology), Michael Stickney (earthquakes and active faults), Wayne Sutherland (Pleistocene caves), and Alan VerPloeg (museums).

Several of these people also compiled or helped compile some of the maps and others provided original materials from which the maps were created. They are credited in the appropriate places in the text, but I would like to make a special point here that this book would not exist without the work of these authors and others. It was possible to do this series of maps only because so much of the basic mapping of different aspects of Wyoming's geology and related features had already been completed.

With the exception of Wilbur Knight's 1900 geologic map, the LANDSAT map, and the computer-generated topographic map, the maps in this book were produced by Geological Survey of Wyoming cartographers. Fred H. Porter, III, Betty S. Wills, and especially Phyllis A. Ranz applied their skills to create these sometimes very intricate pages. Block diagrams and other artwork were drawn by Phyllis Ranz, whose enthusiasm for this book matched mine from the beginning.

A preliminary version of *Wyoming geomaps* was displayed in a poster session at the Geological Society of America national meeting in Denver, Colorado in October, 1988. Visitors to the display offered helpful advice and encouragement and several indicated they planned to produce similar publications for their states. I hope they do.

Sheila Roberts
March 8, 1989

CONTENTS

GEOLOGIC TIME SCALE

AGE[1] (in millions of years)	EON	ERA	PERIOD	GEOLOGIC EVENTS IN WYOMING	IMPORTANT RECORDS OF LIFE ON EARTH
	PHANEROZOIC	CENOZOIC	QUATERNARY		Diversification and spread of mammals; grasses widespread.
66.4	PHANEROZOIC	CENOZOIC	TERTIARY	Complex history (see expanded scale below).	
100; 144	PHANEROZOIC	MESOZOIC	CRETACEOUS	Last marine seaway across Wyoming; shoreline fluctuated west to east; sandstones deposited near shore interfinger into thick, dark marine shales; thick layers of volcanic ash; Laramide orogeny began to form uplifts late in period, especially the Overthrust Belt.	Expansion of flowering plants; mollusks and foraminifera abundant in oceans; extinction of many groups including dinosaurs and ammonites at the end of the period; first primates.
200; 208	PHANEROZOIC	MESOZOIC	JURASSIC	Marine seaway in Early Jurassic, limestone common; later, the sea withdrew and deposition was by streams and lakes; volcanic ash from remote western sources.	Height of the Age of Dinosaurs; earliest record of birds; cycads and conifers dominant plants; marine reef-building.
245	PHANEROZOIC	MESOZOIC	TRIASSIC	Marine seas in west left limestone; shallow seas in central and eastern Wyoming left red siltstones and sandstones, thin limestones, and gypsum.	First dinosaurs, mammals, marine reptiles, flying reptiles.
286	PHANEROZOIC	PALEOZOIC	PERMIAN	Variable marine and nearshore conditions of deposition; redbeds, thin limestones, and gypsum; marine limestone, chert, and organic phosphatic shales in western Wyoming.	Spread of conifers; expansion of reptiles; giant amphibians; widespread extinction of marine life at the end of the period.
300; 320	PHANEROZOIC	PALEOZOIC	PENNSYLVANIAN	Ancestral Rocky Mountains rose in Colorado with some uplift extending into Wyoming; sandstones common, some windblown sands.	Earliest primitive reptiles; coal-forming forests widespread, first conifers; giant dragonflies.
360	PHANEROZOIC	PALEOZOIC	MISSISSIPPIAN	Widespread warm marine seas; thick sequences of fossiliferous limestone.	Spread of amphibians; corals, crinoids, bryzoans, and brachiopods abundant in shallow seas; coal-forming forests on land.
400; 408	PHANEROZOIC	PALEOZOIC	DEVONIAN	Early in period rivers cut channels in older rocks; later marine deposits include sandstones, shales, limestones (coral reefs locally).	Age of Fishes; appearance of amphibians; earliest forests, first seed plants; earliest insects.
438	PHANEROZOIC	PALEOZOIC	SILURIAN	Almost no geologic record in Wyoming. One locality in the southern Laramie Mountains preserves fossiliferous limestone.	Earliest record of land plants and animals; marine reefs common, eurypterids abundant.
500; 505	PHANEROZOIC	PALEOZOIC	ORDOVICIAN	Shallow, warm marine waters covered area; thick sequence of dolomite, local basal sandstone.	Primitive jawless fishes (first known vertebrates); continued diversification of invertebrates.
570	PHANEROZOIC	PALEOZOIC	CAMBRIAN	Invasion of marine waters across continent from west; thick sequence of sandstone, shale, and limestone in west, thinning to east.	First shelly fauna of marine invertebrates including trilobites, brachiopods, sponges, bivalves, others.

major unconformity

The Precambrian is not shown to scale. It would be about three feet long at the scale shown above.

Million years		PERIOD	GEOLOGIC EVENTS IN WYOMING	IMPORTANT RECORDS OF LIFE ON EARTH
1,400; 2,500	PRECAMBRIAN	PROTEROZOIC EON	Rocks preserved only in southeastern Wyoming. Continued crustal growth and deformation of basement rocks; igneous intrusion. Late Proterozoic erosion.	First single-celled life with cell nuclei and soft-bodied multicellular life; stromatolites.
4,600	PRECAMBRIAN	ARCHEAN EON	The Wyoming Archean crust formed.	Origin of life; single-celled life lacking cell nuclei, bacteria and blue-green algae.

Expanded from above

AGE (Million years)	PERIOD	EPOCH	GEOLOGIC EVENTS IN WYOMING	RECORDS OF LIFE
0 – 0.01	QUATERNARY	HOLOCENE	Wyoming today	Modern plants and animals.
0.01 – 1 – 1.6	QUATERNARY	PLEISTOCENE	Glacial and interglacial episodes; Teton Mountains growth continued; volcanic and hydrothermal activity in Yellowstone National Park.	Large Ice-Age mammals (mammoths, mastodons, bison, giant sloths, cave bears, etc.). Dawn of modern humans. Disappearance of many gigantic forms near the end of the epoch.
Scale Change				
1.6 – 5.3	TERTIARY	PLIOCENE	Normal faulting; Teton Mountains; regional uplift and erosion.	Ancestral hominids.
5.3 – 23.7	TERTIARY	MIOCENE	Continued continental deposition; major drainages established, volcanic activity in northwest.	Development of many modern mammal groups; grasslands widespread.
23.7 – 36.6	TERTIARY	OLIGOCENE	Airborn volcanic ash from Great Basin area covered all but high mountains.	Replacement of older mammal groups by newer forms.
36.6 – 50 – 57.8	TERTIARY	EOCENE	Mountain-building uplift of Laramide orogeny completed; erosion to mature landscape; major volcanic activity in Absaroka Volcanic Plateau.	First primitive horses, camels, elephants, and other large mammals.
57.8 – 66.4	TERTIARY	PALEOCENE	Height of Laramide orogeny, faulting created basins and mountains across Wyoming.	Primitive mammals evolve rapidly; sharks abundant.

INTRODUCTION

The facing page is a reduced version of the first printed geologic map of Wyoming, by Wilbur C. Knight. In 1900, Dr. Knight was the *de facto* first State Geologist and a professor at the University of Wyoming. Obviously, a lot was known about Wyoming geology by 1900, but it was actually just a beginning. You can get a sense of the progress of geologic knowledge of the State by comparing this map to the geologic map on page 6 and an even better perspective if you see it next to the wall-sized *Geologic map of Wyoming* by Love and Christiansen (1985, scale 1:500,000). So much information is available that it is impossible to compile it all on a single map of any scale, much less this page-size presentation. Therefore, the following pages provide a useful option — separate bits of information on maps of the same scale compiled in the same book.

The maps are printed at the same scale to facilitate comparisons. However, please note the information came from many sources. Different scales of source maps, different authors' interpretations, and other factors should be considered as you make your comparisons. Also, the scale itself (about 1:2,640,000), while very convenient for an overview of Wyoming, does not allow presentation of detailed information; many boundaries and units are quite generalized.

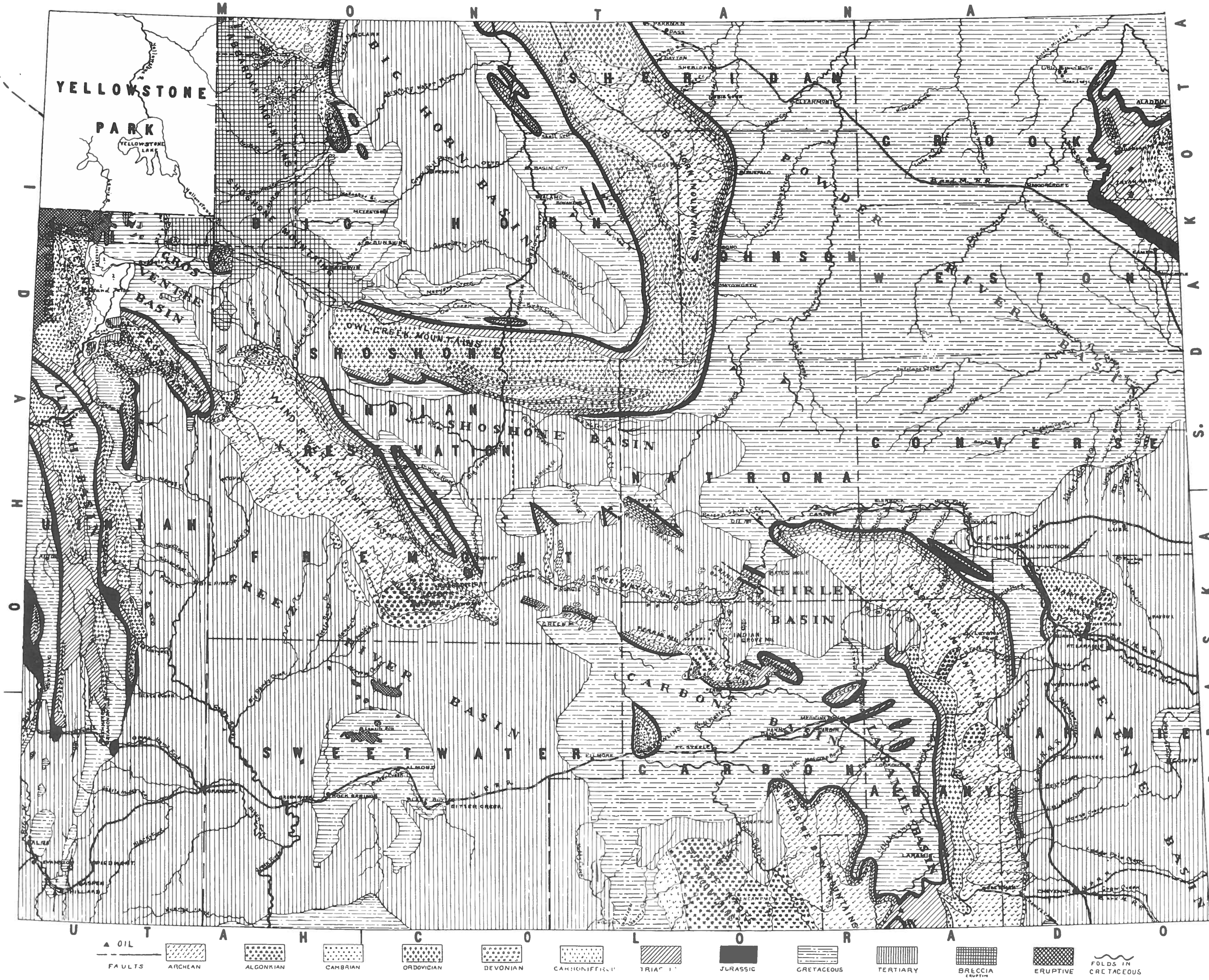
All this mapping and research have gone on because geology is so important to Wyoming. Wyoming's number-one source of wealth is extractive industries. Oil, natural gas, and coal head the list and make the State a major producer of energy for the country. Ranching and farming exist in Wyoming in places where geologic and climatologic events left a veneer of soil that supports grasslands or cultivated crops. Tourism flourishes because of the scenery created by the State's unique (some would say bizarre) geologic history. Geologic wonders like Yellowstone National Park, the Grand Tetons, Fossil Butte, and Devils Tower attract international attention.

Many of the State's problems are geologic too. The sometimes insufficient availability of water for drinking, agriculture, industry, and recreation is almost as much a geologic phenomenon as it is climatologic. Earthquakes, landslides, and floods are the result of geologic conditions whose hazards can be aggravated or alleviated by human activities. The sometimes drastic fluctuations in Wyoming's economy result from the State's dependence on world markets for the products extracted from the Earth.

The maps are spatial representations, but the study of geology is always a voyage through time as well. There are two charts in this book to help orient readers in geologic time. The one on this page focuses on the age of major events in Wyoming's geologic history and the evolution of life. The back inside cover contains a chart that emphasizes the age of Wyoming's valuable geological resources. The charts are modifed from originals in Blackstone (1988), and Hausel (1986). Information on ancient life is from Carroll (1988), Lambert (1985), Steel and Harvey (1979), and Tidwell (1975).

RECONNAISSANCE GEOLOGICAL MAP OF WYOMING

By Wilbur C. Knight, 1900



TOPOGRAPHIC/SHADED RELIEF MAP OF WYOMING

This topographic/shaded relief map beautifully illustrates a new technology of mapping with computers. To create this map, a set of ground elevations (every 30 seconds of latitude and longitude) was entered into a computer data base from U.S. Geological Survey files. The computer operator then determined a set of colors to correspond to different elevations (see explanation). In order to create the 3-dimensional appearance, the operator chose a point of view from somewhere outside the map (in this case, straight above it) and a sun angle to establish shadows (in this case, from the northwest). Processing of the data using these parameters yielded a color-shaded 35-millimeter slide of the image seen on this page. Finally, a computerized scanner separated the slide into its 4-color components (red, blue, yellow, and black) and enlarged the image to produce the negatives from which the page was printed. In this case, lakes and reservoirs were added from a separate overlay but they could also have been generated by the computer from a separate data set.

The result is a map of intricate detail (for this scale) that has the visual power of a photograph although it was created entirely from recorded elevations. The mountains, valleys, basins, river drainage patterns, reservoirs, and lakes all appear. Similar technological "magic" is being applied to all sorts of geologic mapping across the country. Some of the other maps in this book, notably the magnetic and gravity anomaly maps (pages 12 and 14), were at least partly created on computers.

Most of Wyoming is comprised of either mountains or high plains. The State's average elevation is a very high, 6,100 feet above mean sea level, second only to Colorado in the United States. The highest point is Gannett Peak in the central Wind River Range (13,804 feet), and the lowest point is where the Belle Fourche River leaves the state in northeastern Wyoming (3,125 feet).

Wyoming is frequently discussed in terms of its physiographic provinces (see diagram). Except for the extreme northwest corner, most of northwestern and western Wyoming falls in the middle Rocky Mountains province. The northwestern corner contains the boundary between the middle and northern Rocky Mountains. Mountains extending into eastern Wyoming from Colorado on its southern border are the north end of the southern Rocky Mountains province. Highlands in the northeastern corner of the state comprise the part of the Black Hills province that extends into Wyoming. The large relatively flat region between the Black Hills and the middle and southern Rocky Mountains is the Great Plains province. The high basin country that makes up most of south-central Wyoming is the Wyoming Basin province. The Continental Divide splits Wyoming along a southeast to northwest line, looping around the internal drainage of the Great Divide Basin.

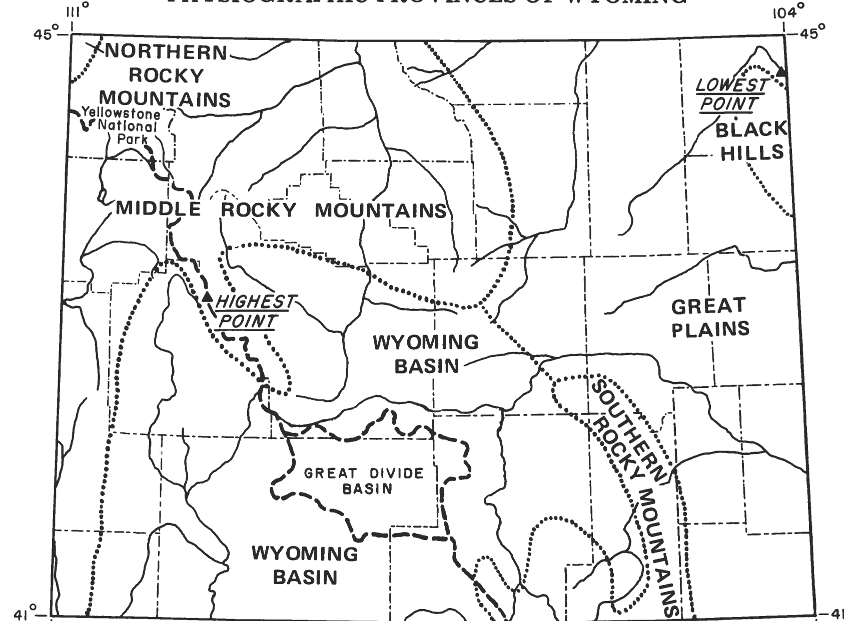
Much of Wyoming's topography can be understood in terms of the structure and composition of the underlying rocks (see maps on pages 6 and 8 especially). The erosive activities of rivers (page 30) and glaciers (page 28) leave their distinctive marks on the land. Soils and vegetation (pages 32 and 34) affect and are affected by topography. Current topography is simply the most recent portrait of a constantly changing surface.

MAP EXPLANATION

Elevations, in feet above sea level, are depicted with colors:

White	=	above 11,000 feet
Gray	=	above 10,000 and below 11,000 feet
Brown	=	above 9,000 and below 10,000 feet
Yellow	=	above 5,000 and below 9,000 feet
Green	=	above 3,000 and below 5,000 feet

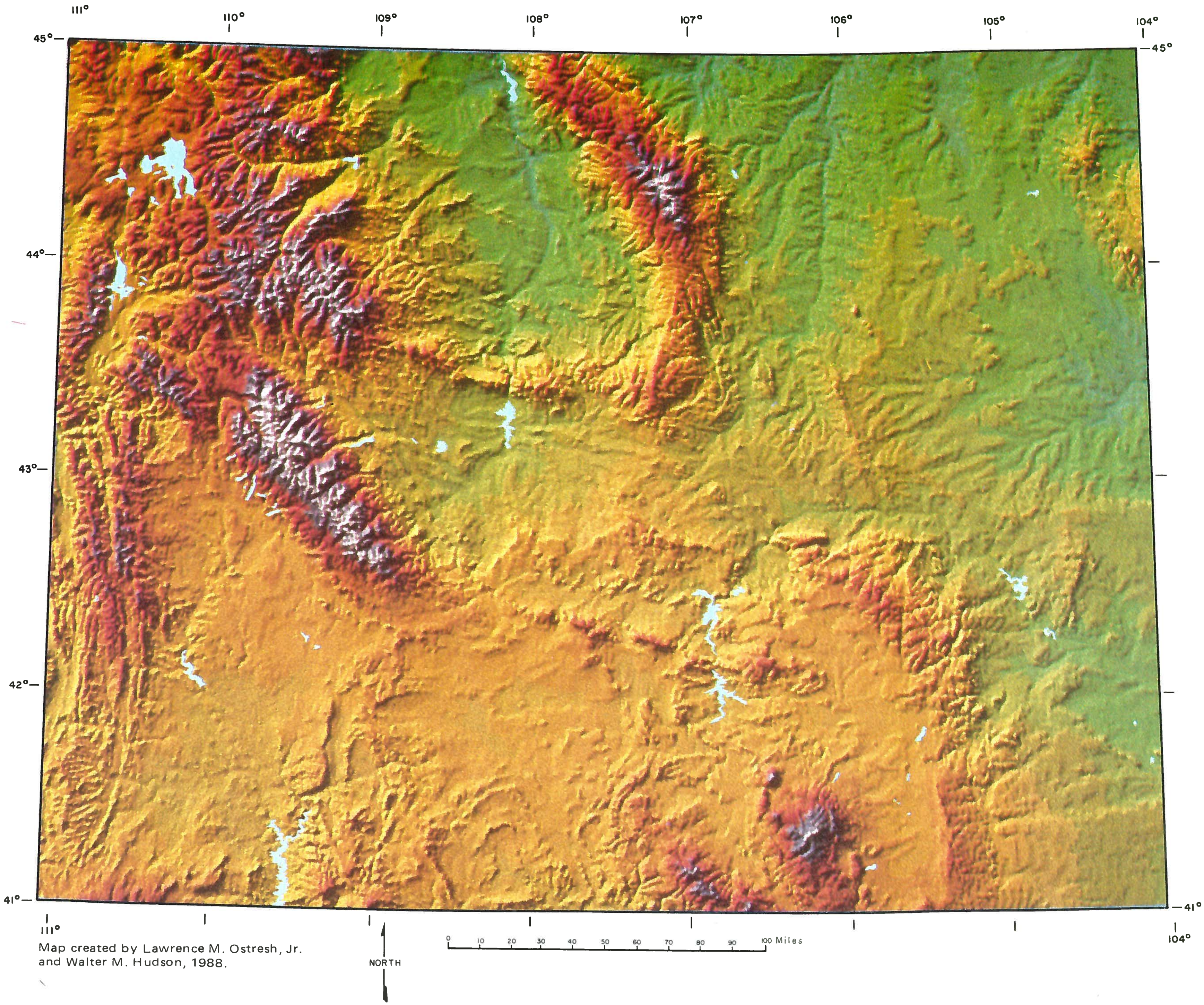
PHYSIOGRAPHIC PROVINCES OF WYOMING



From Blackstone (1988).

EXPLANATION

- ·············· Generalized boundary of major physiographic province
- – – – – Continental Divide
- –·–·–·– County boundary
- ▲ Highest and lowest elevations in the state



Map created by Lawrence M. Ostresh, Jr.
and Walter M. Hudson, 1988.

GEOLOGIC MAP OF WYOMING

MAP EXPLANATION

Age in millions of years

CENOZOIC IGNEOUS ROCKS

- Quaternary, Pliocene, and Miocene rhyolite and basalt; some intrusives
- Upper Tertiary to Cretaceous(?) intrusive rocks; some extrusives
- Eocene Absaroka Volcanic Supergroup

SEDIMENTS AND SEDIMENTARY ROCKS

Cenozoic

- Quaternary unconsolidated sediments
- Lower Quaternary, Pliocene, and Miocene
- Oligocene
- Middle Eocene; some Upper Eocene
- Lower Eocene
- Paleocene

66.4

Mesozoic

- Upper Cretacous
- Upper and Lower Cretaceous
- Lower Cretaceous; some Jurassic
- Jurassic; some Lower Cretaceous
- Triassic

245

Paleozoic

- Permian and Pennsylvanian; some Mississippian and Triassic
- Cambrian, Ordovician, Devonian, and Mississippian

570

IGNEOUS AND METAMORPHIC ROCKS

Precambrian

Major unconformity

- Middle Proterozoic intrusive rocks
- Early Proterozoic igneous and metamorphic rocks

2,500

- Archean igneous and metamorphic rocks

MAJOR FAULTS

- Fault (dotted where concealed)
- Thrust fault; teeth on upper plate (dotted where concealed)

A geologic map is a portrait of the surface of the Earth in the same way a photograph is a portrait of the surface of your face. This map of Wyoming shows, in a very general way, the distribution of rocks and sediments across the face of Wyoming, scrubbed clean of its thin veneer of plants and soil. It is an old, wrinkled face and at first glance it may look hopelessly complex. The different colors show the different types and ages of rocks and they tell a wonderful story of the State's geologic history. In general, rocks exposed at the surface are progressively younger away from the mountain cores. On the map, rocks are divided into three major units based on age and rock type:

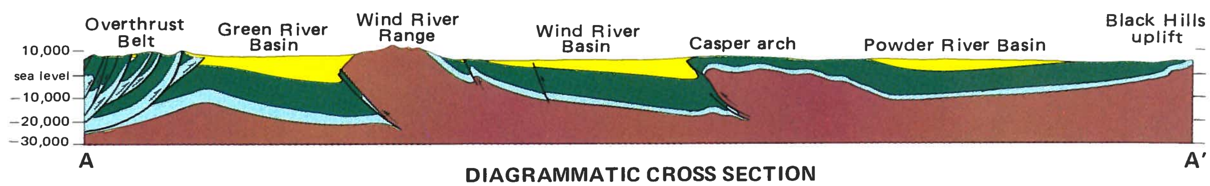
(1) Precambrian igneous and metamorphic rocks are the oldest in Wyoming, exposed only in the cores of mountain ranges where all the younger rocks have eroded off of them. The cross section shows they are actually continuous in the deeper crust. Some of these rocks have very complex histories, having formed from other rocks that were changed by extreme heat and pressure. Others crystallized from molten material. When the Precambrian rocks formed, life on Earth was mostly single-celled, microscopic bacteria and algae, which are preserved in Wyoming only in the Medicine Bow Mountains. Elsewhere, rocks that would have contained fossil life have been recrystallized.

(2) Paleozoic, Mesozoic, and Cenozoic sediments and sedimentary rocks are exposed over much of the rest of the State. Paleozoic and Mesozoic rocks often appear as thin lines of color on the map because they are tilted up on edge (see the cross section). Sandstones, shales, and carbonate rocks of this age contain fossils that record most of the evolution of life from the first appearance of animals with shells and skeltons through the dinosaurs. Most of the Paleozoic rocks formed from sediments deposited in or very near ancient seas that covered Wyoming. During Mesozoic time, seas advanced and retreated across Wyoming, leaving alternating marine and continental sediments.

Cenozoic unconsolidated sediments include nonmarine deposits left by glaciers; windblown sand and dust; river, stream, and lake deposits; landslide debris, and other uncemented earth materials. Cenozoic sedimentary rocks cover relatively unbroken areas of the basins. They preserve debris eroded from the mountain ranges when they were young; volcanic ash blown across the State; and sediments that collected in rivers, lakes, and swamps. Most of the evolution of mammals occurred at the same time the Cenozoic basins were filling and Wyoming has some excellent fossil sites of this age.

(3) Cenozoic igneous rocks in the northwest corner of the state formed during two separate episodes. The Absaroka Mountains Volcanics erupted first. Much later, magma flowed or exploded out of the Earth and covered most of the older rocks in the Yellowstone National Park area. Many of the Cenozoic sedimentary rocks in Wyoming contain volcanic ash from eruptions in Wyoming and in areas south and west of the State. Cenozoic igneous rocks also occur in the Black Hills area and a few other scattered locations in Wyoming.

Each of the three major units is divided into smaller units based on age and rock type, but the scale of the map does not allow representation of rock *formations*, which are the units usually mapped by geologists. The map also shows the location of major faults (breaks in the Earth's crust along which there has been displacement) and the cross section gives a generalized view down into Wyoming's layered rock crust.

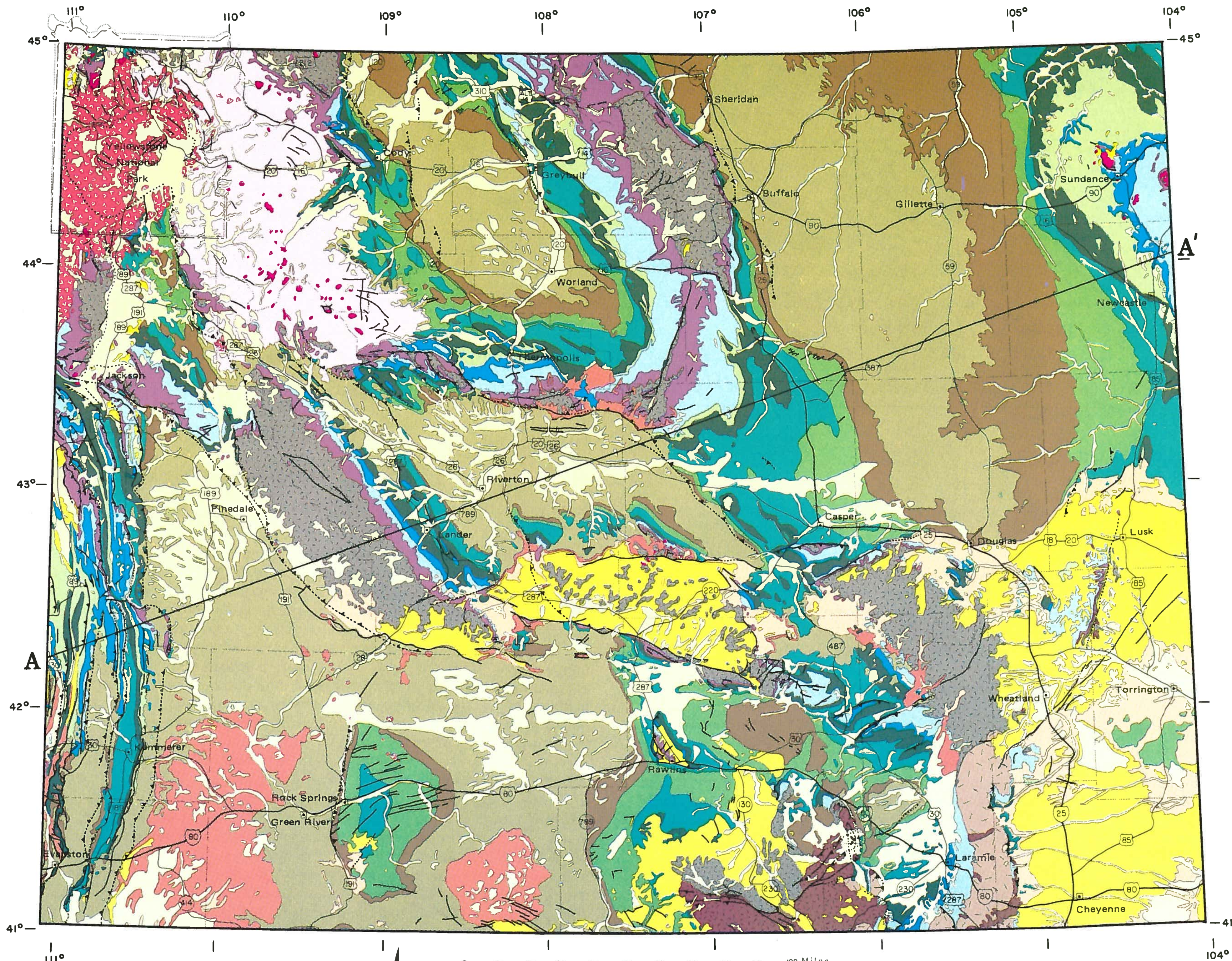


DIAGRAMMATIC CROSS SECTION

A-A' Generalized interpretation of subsurface rocks (line of section shown on map). Vertical exaggeration 4:1; horizontal scale of cross section is shortened. (Modified from Christiansen, 1986.)

Explanation

- Cenozoic
- Mesozoic
- Paleozoic
- Precambrian
- Fault; arrow indicates relative movement



Map modified from Love and Christiansen (1985) and Christiansen (1986).

Cartography by Phyllis A. Ranz

STRUCTURE MAP OF WYOMING

Folds and faults are the periods, commas, question marks, and exclamation points of the Earth's geologic story that tell us how the rock units relate to each other and to the surface. This map shows some of the major structural features of Wyoming and includes both ancient, inactive structures and ones that have been active in the geologically recent past. The accompanying block diagram depicts a cutaway view of typical structures found in the State.

The present surface of Wyoming is largely a series of rugged mountain range "islands" emerging from a "sea" of high flat basins and plains. When you look at this varied surface it is hard to imagine the scene in past geologic eras, when most of the State was practically flat land near or below sea level.

Most of the present large-scale topography of Wyoming reflects geologic structures that developed during the latest Cretaceous and earliest Tertiary mountain-building event known as the Laramide orogeny. In westernmost Wyoming, a series of west dipping thrust faults elevated sheets of rocks piggyback on each other. The more erosion-resistant rocks in those sheets form ridges today. Valleys occur where less resistant strips of rock eroded or where more recent faulting has dropped them down. (On the map, folds, which generally parallel the faults, are not shown in the Overthrust Belt because the map would be too crowded.) The Laramide mountains of central Wyoming are composed primarily of erosion-resistant Precambrian igneous and metamorphic rocks that were elevated above the surrounding basins on thrust faults. Younger rocks, which once covered the Precambrian cores, eroded off during the millions of years that followed faulting. As the mountains rose, the basins folded and dropped, so rocks that formed at the same level before mountain building began are now separated by tens of thousands of feet in some places (see cross section, geologic map). One good example of this on the map is the Wind River Range, which is bounded on the west and south by a large thrust fault and surrounded by deeply folded basins. Most of the basins are relatively flat at the surface because younger sediments have filled in across the folds.

The Sweetwater uplift (Granite Mountains) in central Wyoming appears to be an example of a Laramide mountain range that was uplifted long enough for erosion to expose the Precambrian rocks and then downdropped on normal faults millions of years later. Some Precambrian knobs still protrude from the Tertiary sedimentary rocks that filled in over the old fallen mountain range.

The Teton Range is Wyoming's youngest mountain range. Over the past 10 million years, the valley of Jackson Hole has dropped thousands of feet along a normal fault system, leaving the sheer face of the Tetons on its west side.

The most prominent structure in the northwest corner of this map is the Yellowstone caldera boundary. There, a huge volcanic dome blew out its molten insides and collapsed, leaving an irregular scarp around the edge of the collapsed dome. The structure shows up well on this map, but it is not as obvious on the ground and it took years of study before geologists were able to recognize and map it.

MAP EXPLANATION

- Cenozoic igneous intrusive rocks
- Tertiary and Quaternary volcanic rocks
- Precambrian basement rocks
- Yellowstone caldera

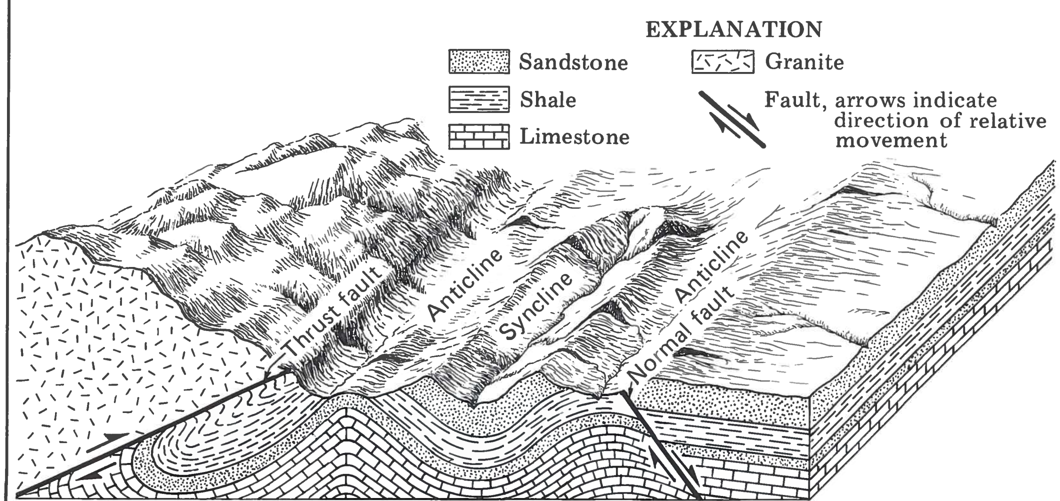
FAULTS (dashed = approximate or concealed)

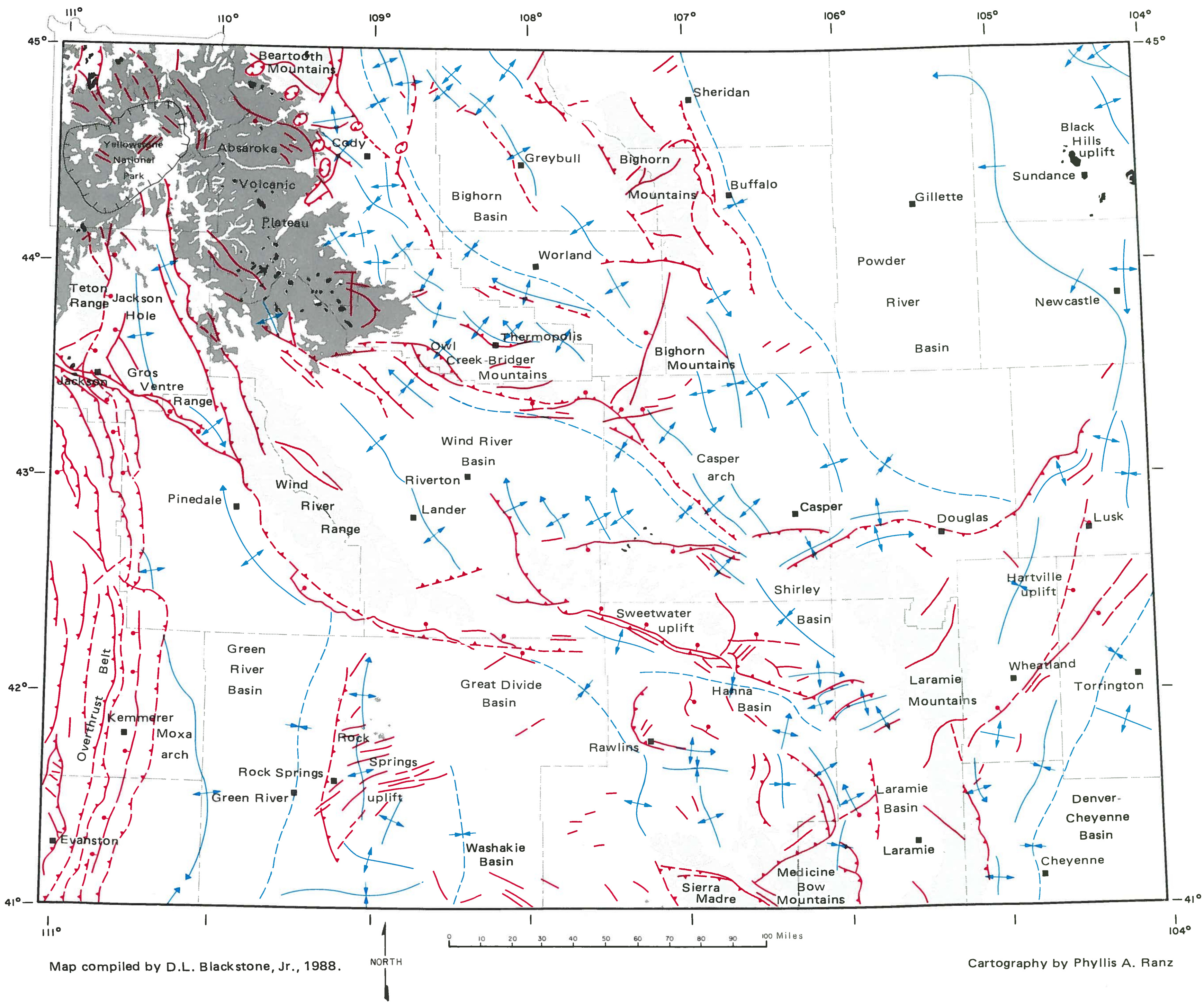
- Thrust fault, barb on upthrown side
- Normal fault, bar and ball on downthrown side
- Fault of unspecified displacement

FOLDS

- Anticline, end arrow indicates plunge
- Syncline, end arrow indicates plunge
- Monocline, end arrow indicates plunge
- Basin axis

BLOCK DIAGRAM OF SOME COMMON GEOLOGIC STRUCTURES





Map compiled by D.L. Blackstone, Jr., 1988.

Cartography by Phyllis A. Ranz

PRECAMBRIAN BASEMENT MAP OF WYOMING: OUTCROP AND STRUCTURAL CONFIGURATION

MAP EXPLANATION

LITHOLOGIC UNITS[1]

Precambrian rock outcrop.

Tertiary and Quaternary igneous rock outcrop.

FAULTS (shown where they intersect Precambrian rocks at the surface or in the subsurface).

Thrust fault, sawteeth on upthrown side; dashed where inferred.

Normal fault, ball and bar on downthrown side; dashed where inferred.

High-angle fault, bars on upthrown side; dashed where inferred.

Fault, movement unspecified; dashed where inferred.

CONTOURS

+10 Elevation contour on top of Precambrian basement, in feet above (+) or below (—) mean sea level. Contour interval = 5,000 feet. Contour numbers represent thousands of feet.

-20 Contour in footwall of thrust.

+15 Contour restored to pre-erosion elevation

DATA POINTS

• Well drilled to the Precambrian.

○ Well drilled to the Cambrian (Precambrian elevation estimated).

△+13,766 Elevations of Precambrian rocks in some of the highest mountain peaks (in feet).

Yellowstone caldera boundary.

[1]Outcrop modified from Love and Christiansen (1985).

In Wyoming geology, "basement" refers to the Precambrian igneous and metamorphic rocks that underlie the younger layered sedimentary or volcanic rocks. They are the crustal foundation (basement) upon which all the younger rocks were deposited.

This map depicts surface exposures of Precambrian basement rocks (mostly in the centers of the highest mountain ranges) and the configuration of the basement rock surface where it is buried beneath younger rocks and sediments. Contours show how deep the bottoms of some of the basins are and how much relief exists between Precambrian rocks in the high mountains and in the basins. Note that the contours do not describe depth from the surface, but elevation above or below sea level.

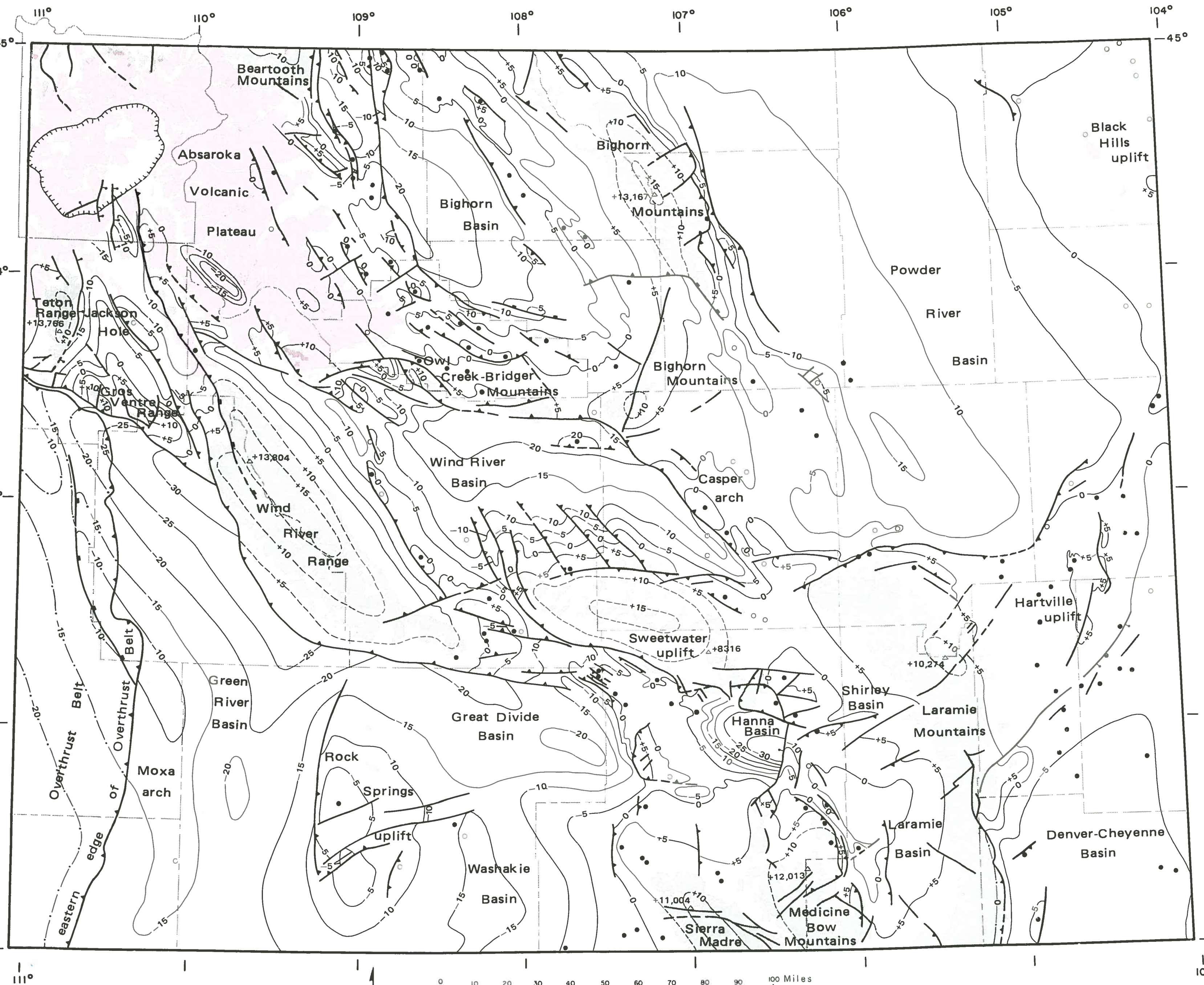
Contours are widely spaced where basement rocks dip gently under the overlying rocks, for example in the central Powder River Basin. More closely spaced contours indicate steeper dips, for example along the south and east sides of the Hanna Basin. Contours may be broken or offset suddenly across faults; this relationship is dramatically illustrated along the fault that bounds the Wind River Range on the west and southwest, where contours demonstrate more than 35,000 feet of relief between the basement surfaces in the basin and mountains east of Pinedale. The complicated pattern of faults in the Overthrust Belt, seen on the structure map of this series, does not appear here. Thrust faulting in extreme western Wyoming primarily involves younger rocks overlying the Precambrian basement; therefore the map simply depicts the westward dip of the basement and the eastern edge of the Overthrust Belt.

A blanket of volcanic rocks in the northwest corner of the State covers much of the evidence needed to predict the depth to Precambrian rocks and data from wells is not available in this area. It is difficult to "see" under the volcanics even with geophysical methods.

To create the map, the author, D.L. Blackstone, Jr., used data from wells that were actually drilled to the Precambrian or that reached depths where the thickness of rocks overlying the basement could be reliably estimated. Locations of wells that reached Precambrian or Cambrian rocks are provided on the map. Dr. Blackstone also used reflection seismic, magnetic, and gravity data.

This view of the outcrop and probable location of buried basement rocks helps us see the underlying structure of the upper crustal rocks in Wyoming. That information is very useful for companies interested in drilling oil and gas wells because these valuable resources usually occur in the younger rocks overlying basement and because oil and gas are sometimes trapped in structures that are related to movements in the basement rocks, for example, in anticlines overlying faulted basement uplifts.

The map does not describe the specific composition of the basement rocks, a great variety of igneous and metamorphic rock types ranging in age from possibly greater than 3.4 to about 1.4 billion years old. Most of Wyoming's Precambrian basement belongs in the "Wyoming Province," an ancient crustal block of rocks, most of which are older than 2.5 billion years. In the extreme southeast corner, younger Precambrian rocks form the crustal basement. Precambrian rocks in Wyoming contain many important deposits of metals and precious and semiprecious stones. (For a review and list of references see Houston, 1986.) Wyoming jade originated as vein- and pod-shaped masses in Precambrian rocks. The iron ore deposits mined near Hartville and Lander, the copper deposit mined near Encampment, and numerous gold occurrences are also in Precambrian rocks.



Map modified from Blackstone (1989).

Cartography by Phyllis A. Ranz

GRAVITY ANOMALY MAP OF WYOMING

Gravity measurements provide data on the distribution of rocks of different densities in the Earth's crust and upper mantle. This is useful because we cannot actually see into the Earth, except where it has been drilled for oil, water, minerals, or for some other reason, and even then the information is spotty and limited to relatively shallow depths. Gravity data (measured on the surface) can help resolve questions about the subsurface structure and composition of the Earth.

By the middle of the 18th Century, scientists had begun to understand that there are variations in the force of gravity at different places on the Earth's surface. When an object is weighed at the location of a gravity high it will weigh slightly more than when it is weighed at the location of a gravity low. Very sensitive instruments, called gravimeters, can measure small differences in the force of gravity at the Earth's surface. Differences in rock density, elevation, latitude, and terraine all affect the measured gravitational force. To make this Bouguer gravity map, the contributions of elevation, latitude, and terrain have been theoretically subtracted out so that the remaining information on the map is primarily related to rock densities in the outer 20 miles of the Earth. Gravity highs suggest rocks of high density and gravity lows suggest rocks of low density, but gravity data do not give definite information about the sizes, shapes, exact locations, and compositions of rock bodies. This geophysical tool is usually combined with other types of information to decipher the subsurface composition and structure.

Regional gravity anomaly maps like this one of Wyoming have been used to map the configuration of crystalline basement rocks, the sizes and shapes of sedimentary rock basins, the distribution of large igneous rock bodies, and other large-scale features of the Earth. Smaller scale gravity maps, made with measurements taken at closer spacings, might help locate a dense ore body, establish the location of a concealed anticline that could be drilled for oil, or define the trace of a buried fault.

As you have already seen on the structure and geology maps, Wyoming is composed of alternating sedimentary basins and uplifted mountain ranges cored by Precambrian crystalline rocks. These structural features are reflected in the gravity map. Although the contours are gravity values and not topography, there is a strong correlation of highs with mountain ranges and lows with basins. For example, the Wind River Range appears as a gravity high between the Green River Basin on the west and the Wind River Basin on the east. The Bighorn Mountains high is surrounded by Bighorn, Powder River and Wind River Basins lows. The Hanna Basin is a very impressive gravity low, while the Laramie and Medicine Bow Mountains, Sierra Madre, and Rock Springs uplifts are relatively high. However, the topography is not the source of the anomalies. Compared with the mountain ranges, basins have strongly negative gravity anomaly values because the basins are filled with layers of unconsolidated sediments and sedimentary rocks that are less dense than the igneous and metamorphic rocks in the ranges (see rock density chart, this page).

This map contains several anomalies that do not fit the simple basin and mountain model just described. For example, there is a large (blue) gravity low in Yellowstone National Park that cannot be caused by a deep sedimentary basin. The rocks there are lava flows, ash falls, volcanic breccias, and other rocks that do not seem, at the surface, to be significantly less dense than similar igneous rocks that surround them. Some scientists (for example, Eaton and others, 1975; Smith and others, 1977) have suggested that the gravity low may reflect the presence of a low-density plume of hot, probably partially molten, igneous rock at depth. Interpreting gravity maps is complicated, involving sophisticated mathematical modeling, but this information is an essential tool for understanding the Earth.

Average density of crustal rocks, expressed in grams per cubic centimer (water = 1 gram/cubic centimeter). (Modified from Meissner, 1986, p. 26.)

Sediments and Sedimentary Rocks

Unconsolidated sediments		Sedimentary rocks	
Loess	1.6	Sandstone	2.5
Sand	2.0	Limestone	2.6
Soils	1.9	Shale	2.6
Clay	2.2	Dolomite	2.7

Igneous and Metamorphic Rocks Common in the Normal Continental Crust

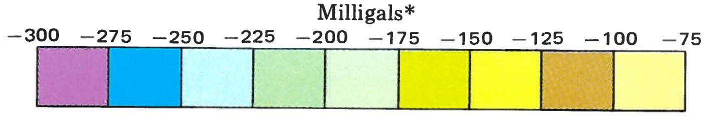
Extrusive igneous		Intrusive igneous		Metamorphic	
Rhyolite	2.5	Granite	2.67	Quartzite	2.6
Andesite	2.7	Diorite	2.85	Schist	2.6
Basalt	2.9	Gabbro	3.00	Gneiss	2.75
				Amphibolite	2.95
				Serpentine	2.85

Upper Mantle Rocks

Peridotite	3.2
Dunite	3.25
Eclogite	3.4

MAP EXPLANATION

Milligals*

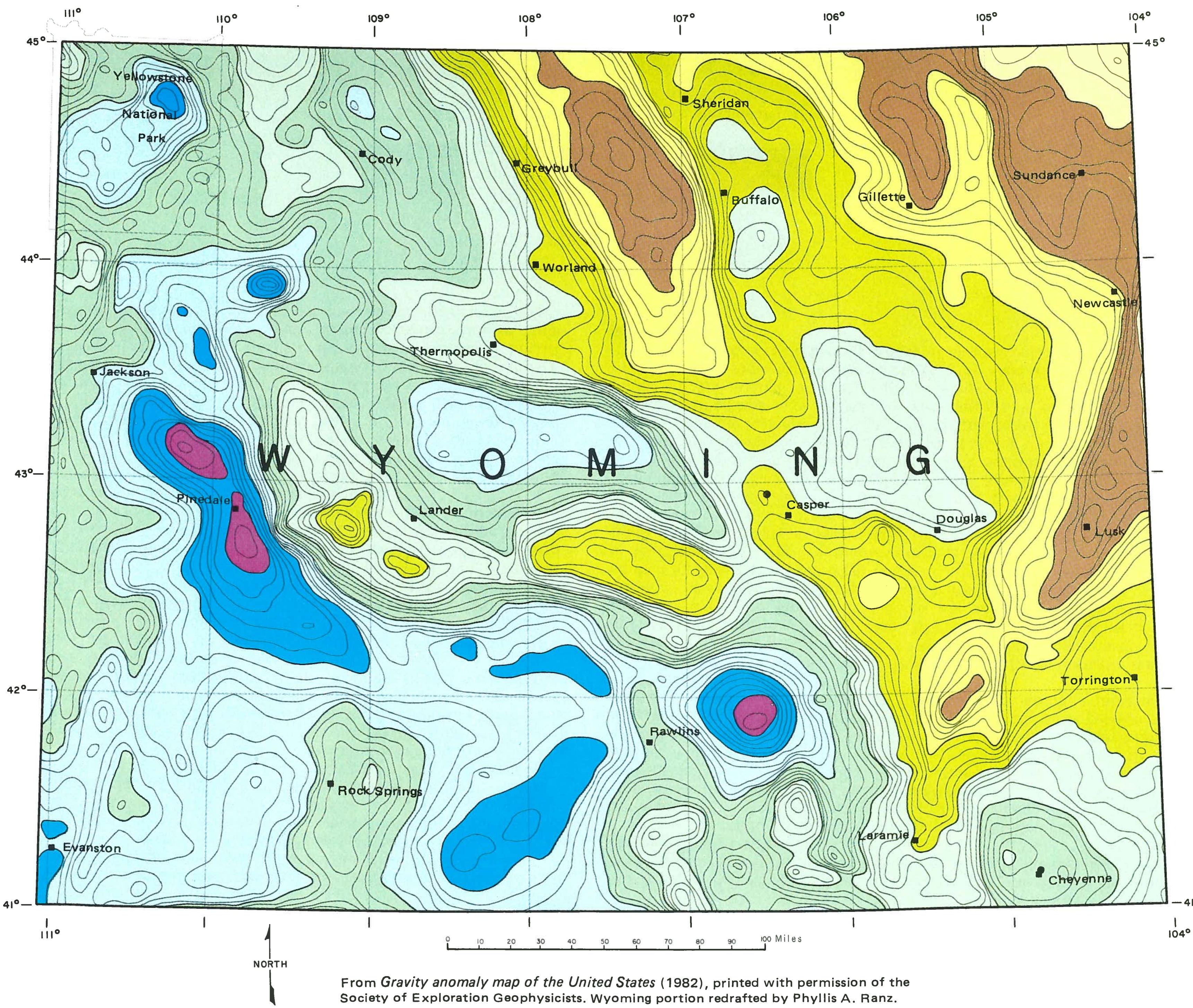


Contour interval 5 milligals.

*Unit of acceleration used with gravity measurements ($1x10^{-3}$ centimeters/second^2).

●

National Geodetic Survey Gravity Base Station



From *Gravity anomaly map of the United States* (1982), printed with permission of the Society of Exploration Geophysicists. Wyoming portion redrafted by Phyllis A. Ranz.

MAGNETIC ANOMALY MAP OF WYOMING

Like gravity, magnetic field measurements provide a geophysical tool for interpreting the subsurface composition and structure of the Earth.

In 1600, an Englishman, William Gilbert, published the first book describing the bipolar geomagnetic field with specific orientations at each point on the Earth's surface. Within 40 years, Swedish miners were using observations of unusual local orientations of the magnetic field to prospect for iron ore (Parasnis, 1986). Magnetite (an iron-oxygen mineral, Fe_3O_4) buried beneath the ground surface caused a detectable deflection of a compass needle. In the late 19th Century, a sensitive device for measuring the different components of magnetic field (magnetometer) was invented and by the early 20th Century, scientists had begun to use magnetic measurements to help locate a whole array of near-surface features including buried faults, igneous rock bodies, salt domes, and meteorites.

Some Earth materials are much more susceptible to magnetization than others. The iron-oxygen minerals (+ or — other elements), specifically magnetite and also titanomagnetite, and the iron sulfide pyrrhotite are the most important of these. They can be responsible for measureable local increases in the total intensity of the Earth's magnetic field and will even retain magnetic properties in the absence of an applied magnetic field. Certain rock types (for example basalt, magnetite-bearing granite, and magnetite iron formation) characteristically contain more of these magnetic minerals than others (for example, limestone and most sandstones).

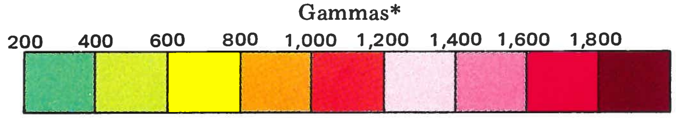
Most modern magnetic surveys measure the total intensity of the magnetic field at different locations and subtract out the normal field value and any perterbation due to small daily fluctuations, magnetic storms, or other sources, to get the anomaly value. Measurements can be taken on the ground, from the air, or from ships. Differences from the normal field are generally attributed to variations in the distribution of rocks and minerals with different magnetic susceptibilities or remanent magnetization (magnetization that was "frozen" into the rock, usually at the time of its formation; Sheriff, 1973). Because the magnetic poles of the Earth occasionally reverse, remanent magnetism can be either the same or the opposite orientation of the current field depending on when the rock formed. The polar orientation of rocks with remanent magnetism may also be altered if the rock is moved, for example during continental drift.

Once the magnetic anomalies are identified, interpretation is aimed at determining the size, shape, depth, polarity, and composition of the anomalous magnetic material. Detailed land-based measurements are used to detect near-surface small-scale anomalies caused by relatively small features like ore bodies, fault zones, and small intrusions. Broader scale aeromagnetic data are more useful in delineating large-scale crustal features. Interpretation of magnetic anomalies must be made in conjunction with other geologic data because magnetic measurements give suggestive, not absolute information about the rocks.

This magnetic anomaly map of Wyoming is part of a magnetic map of the United States that was constructed from diverse sources, mostly total-intensity aeromagnetic anomaly data. Magnetic map interpretation is very complex, but some general observations are possible. For example, Precambrian igneous and metamorphic rocks in Wyoming and elsewhere usually contain more magnetite and other magnetic minerals than sedimentary rocks in the basins. Thus, the Precambrian cores of the Bighorn, Wind River, and other mountain ranges correlate with areas of generally higher anomalous measurements than the basins that surround them. The very high anomalies south and west of Lander probably reflect the presence of metamorphic rocks that contain large quantities of magnetite. A deposit of iron formation in this area was mined by U.S. Steel until 1983. An area of relatively lower magnetic measurements east and north of Laramie (in green) coincides roughly with the location of a large body of igneous rock that is composed primarily of feldspar and is thus not very susceptible to magnetism. The center of Yellowstone National Park is relatively low compared to surrounding areas; some scientists speculate that the rocks at depth are too hot to be magnetized because there is a body of magma beneath the park (Smith and others, 1974).

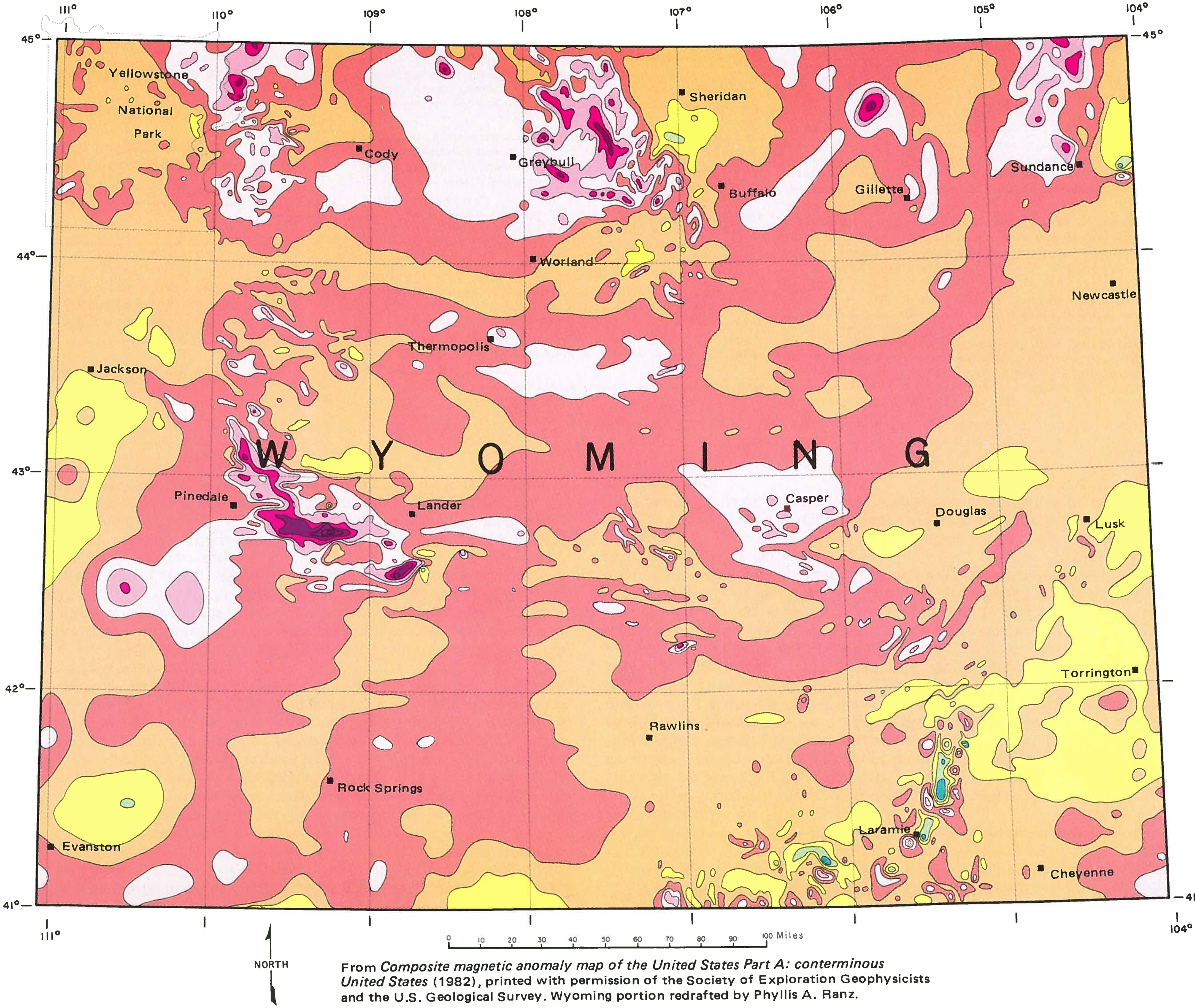
MAP EXPLANATION

Gammas*



Contour interval 200 gammas.

*Unit of magnetic field used with magnetic measurements.



From *Composite magnetic anomaly map of the United States Part A: conterminous United States* (1982), printed with permission of the Society of Exploration Geophysicists and the U.S. Geological Survey. Wyoming portion redrafted by Phyllis A. Ranz.

EARTHQUAKES AND KNOWN OR SUSPECTED ACTIVE FAULTS IN WYOMING

The thin crustal skin of the Earth is constantly being squeezed and stretched by large-scale movements deep within the planet. At times, a sudden movement results in an earthquake. Most earthquakes occur along breaks in the Earth's crust (faults) where rocks move in different directions against each other. Some other causes of earthquakes include movement related to volcanic activity and collapse of underground caverns.

The size of an earthquake can be measured by two very different methods. *Intensity scales* measure the degree of shaking, damage to the works of man, amount of disturbance to ground surfaces, and human and animal reactions. The Modified Mercalli Intensity Scale of 1931 is the intensity scale most often used in this country (see below). Intensity is an inexact measurement that varies with distance from the initial point where the earth moved, building materials and methods, ground stability, and other factors. Most measurements of earthquakes that occurred in Wyoming before the middle 1960s are intensity measurements.

Since the 1960s, most earthquakes have been reported on a *magnitude scale*, which uses a measurement of actual ground movement as recorded on a seismograph. The magnitude scale is open ended; the smallest recordable earthquake is about −2 and the largest ever recorded, the Alaska earthquake of 1964, was about 9 (Bolt, 1978). On magnitude scales, each whole-number increase is a ten times larger earthquake.

Since they are such different measurements, there is no direct correlation between magnitude and intensity, but there is a general relationship (higher numbers refer to bigger earthquakes). In the lower range (about 2-5, II-V), both measurements (of the same earthquake) may produce the same or very close numbers. In the upper range, for the same earthquake, intensity measurement numbers are usually increasingly higher than magnitude numbers.

Most recorded Wyoming earthquakes have occurred in the extreme western part of the State. This region is part of a larger earthquake-prone area known as the Intermountain seismic belt; in Wyoming many of these earthquakes appear to be related to regional stretching (extension) of the Earth's crust (Smith, 1978).

The faults shown are known or suspected to have had recurrent movement in the last 20 million years or so. Although a few of the earthquakes are located along these faults, most of them are not. There are several possible explanations. Relatively small earthquakes, like most of those on the map, record small movements on buried faults, which do not produce noticable displacement at the ground surface. Not all active faults can be observed on the ground, either because they do not extend to the surface or the evidence is obscure. Also, many faults angle away from where they are seen at the surface, so that their positions underground are not directly below their mapped locations. Finally, the major movements that occur during big earthquakes leave striking evidence at the surface but are very infrequent. Perhaps people have simply not been in Wyoming long enough to record many of them. (Note: Old inactive faults that are not expected to be related to recent earthquakes are not shown.)

Scientists cannot accurately predict when earthquakes will occur, but maps like these help predict where they are more likely to happen. Using this information, human activities can be planned to minimize or avoid earthquake disasters.

MAP EXPLANATION

Size* / Date	Magnitude $\geq$5 Intensity $\geq$V	Magnitude $<$5 Intensity $<$V
1871-1965	○	○
1966-1986	●	●

Known or suspected active fault (with surficial expression)

\+ Multiple events in vicinity

3 Number of events at a location

*All magnitudes and intensities are the highest recorded at that location.

MODIFIED MERCALLI INTENSITY SCALE of 1931 (abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing vehicles may rock slightly. Vibration like passing of truck. Duration estimated.

IV. Felt indoors by many during the day, outdoors by few. At night, some persons are awakened. Dishes, windows, and doors are disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing vehicles are rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many persons are frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate damage in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving vehicles.

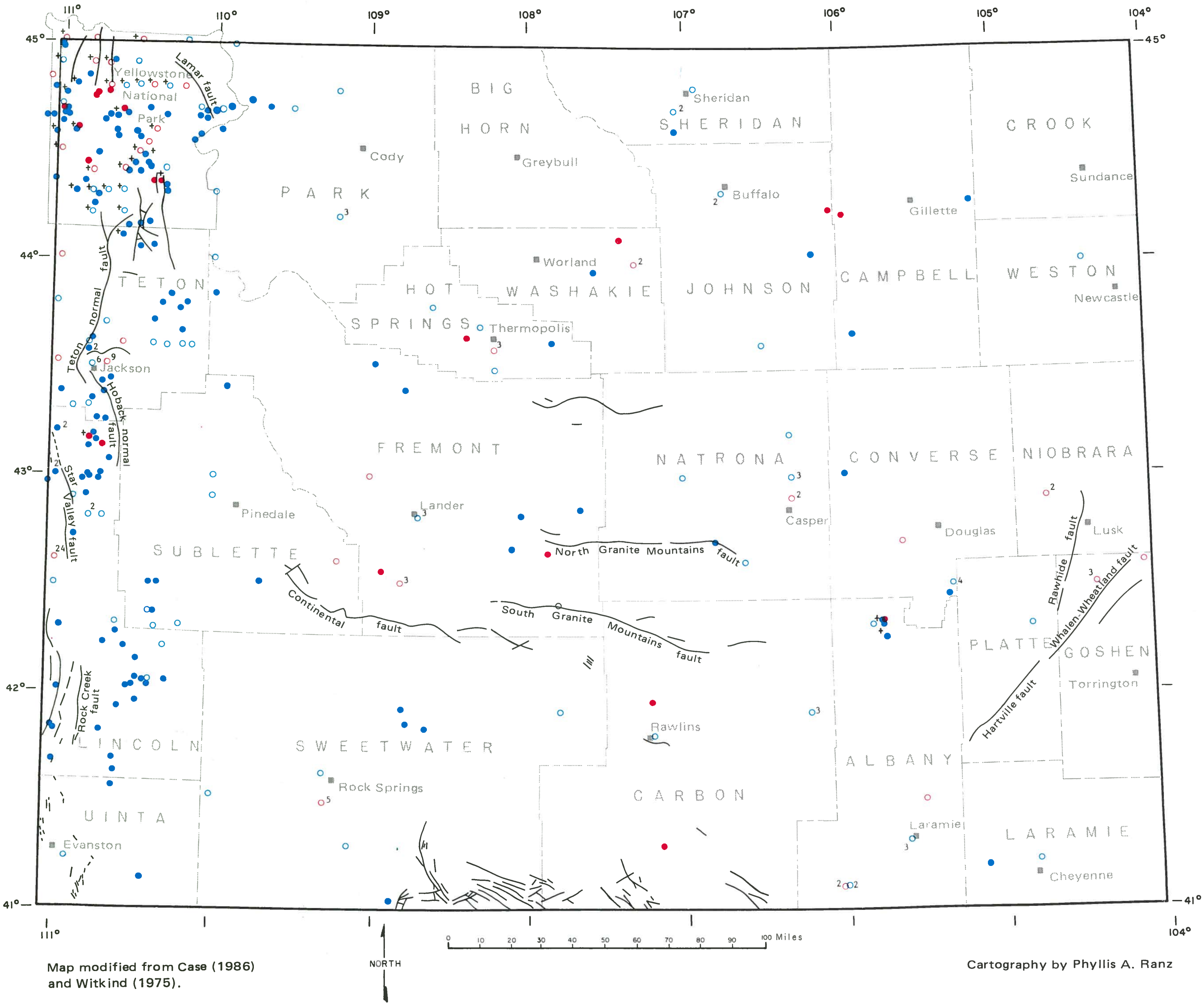
VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse; extensive damage in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels(?). Disturbs persons driving vehicles.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; extensive damage in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable along river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects are thrown upward into the air.



Map modified from Case (1986) and Witkind (1975).

Cartography by Phyllis A. Ranz

GEOTHERMAL MAP OF WYOMING

A natural hot spring is one of nature's most pleasant geological quirks. People all over the world "take the waters" for their health or fun, enjoying the internal heat of the Earth brought to the surface by circulating water. Wyoming probably has more than its fair share of this geothermal phenomena.

The first people to use Wyoming's hot springs were prehistoric Indians who discovered the springs at Thermopolis and Saratoga and probably elsewhere. In 1807, John Colter visited hot springs on the Shoshone River near Cody (known as "Colter's Hell") and possibly in Yellowstone Park. Hot springs near Fort Washaki were noted by Captain Bonneville in his explorations during the 1830s. During the 1840s, Immigrants Wash Tub was a favorite stop on the Oregon Trail. In 1872, the United States government created the first national park in the country shortly after the Hayden Survey described the geysers and other geothermal wonders of the Yellowstone area.

The map shows Wyoming's thermal springs that are warmer than 60°F (15°C). By far the biggest concentration of hot springs is in Yellowstone National Park. Although Wyoming is rarely a hot spot on the nation's weather report, thermal springs and geysers in the Yellowstone area appear to reflect a geological hot spot there, with unusually high crustal temperatures caused by intrusion of molten rock.

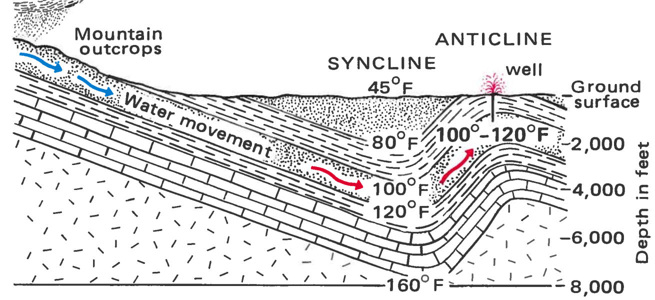
Elsewhere in the State, fold and fault systems circulate water up from such great depths that the normal increase in the Earth's temperature with depth is enough to explain the high temperatures (see Typical Geothermal Systems diagrams). The small red dots on the map signify areas of sedimentary basins that are underlain by hot water. In these areas, deep drill holes encounter hot water in confined aquifers.

The color/temperature designations on the map refer to the hottest recorded temperatures, but temperatures in some springs fluctuate many degrees. Temperature divisions were arbitrarily chosen to represent what might feel cool, warm, and hot to an average person. Because of the scale of the map, springs cooler than 100°F in the Yellowstone National Park area are not shown.

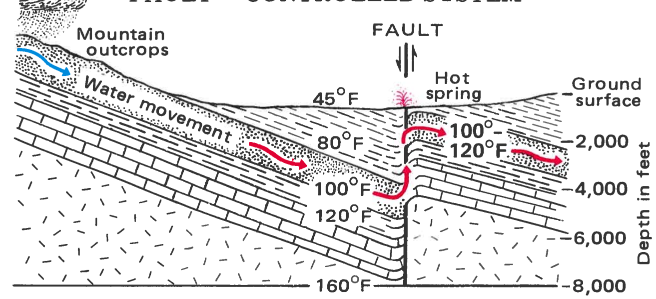
The warm waters of thermal springs often contain great quantities of dissolved minerals and gases, some of which come out of solution at the surface. Deposits of calcium carbonate (travertine), siliceous sinter, and sulfur are often found around active thermal springs or at the sites of extinct springs. These deposits can form spectacular formations like the terraces around Mammoth Springs in Yellowstone National Park or at Hot Springs State Park in Thermopolis. The rotten-egg smell of some hot springs is hydrogen sulfide gas that bubbles out of the water along with carbon dioxide and other gases.

TYPICAL GEOTHERMAL SYSTEMS

FOLD — CONTROLLED SYSTEM



FAULT — CONTROLLED SYSTEM



EXPLANATION

Sandstone (aquifer) | Limestone
Shale | Granite

Cool rainwater or snowmelt (blue arrows) seeps into confined aquifers (porous, permeable rocks surrounded by tight rocks) and flows down into the Earth where it is heated by increasingly hot rocks at depth. The heated water (red arrows) is under pressure from the overlying water column and will flow back toward the surface where its aquifer tilts upward (upper diagram) or where broken rock in a fault zone offers an alternative porous/permable flow route (lower diagram). Many geothermal systems are combinations of faults and folds. The aquifer shown here is sandstone, but limestone is also a common aquifer in Wyoming. (Diagrams modified from Hinckley and Heasler, 1984.)

MAP EXPLANATION

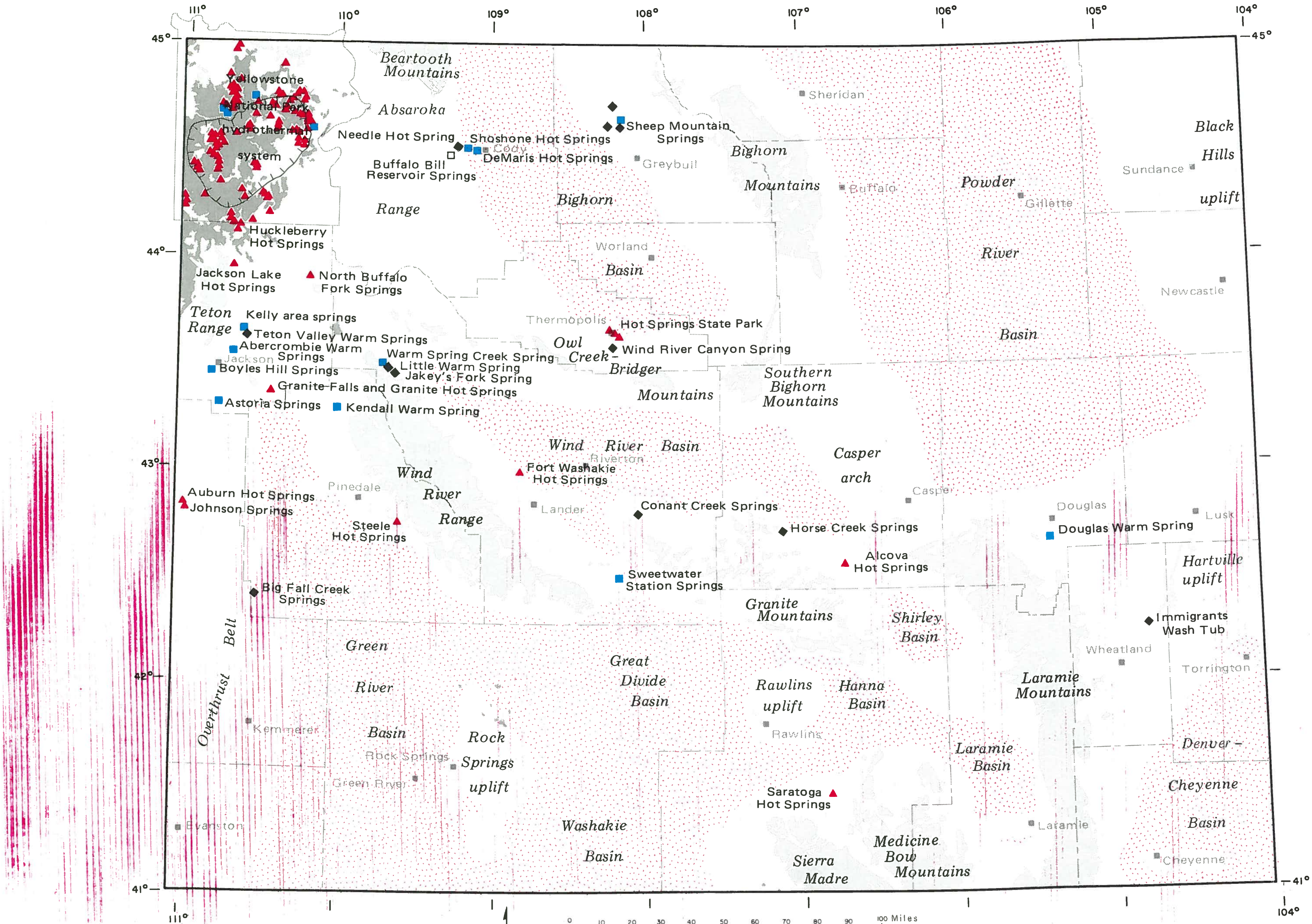
Geothermal springs

- ▲ >100°F (about 38°C)
- ■ >80°F and <100°F (about 27°-38°C)
- ◆ >60°F and <80°F (about 15-27°C)
- □ No recorded temperature available

Springs cooler than 60°F (15°C) not shown.

Base map

- Sedimentary basin areas underlain by water warmer than 120°F
- Area underlain primarily by Yellowstone volcanic rocks (hachured line indicates Yellowstone caldera)
- Precambrian rocks



Map modified from Breckenridge and Hinckley (1978) and Heasler and others (1983).

Cartography by Phyllis A. Ranz

OIL AND GAS MAP OF WYOMING

Oil and natural gas (hydrocarbons), and also coal, are often referred to as fossil fuels because they are derived from ancient life. Whereas coal is mostly the remains of woody plant material, oil and natural gas were derived primarily from lipids (fats, waxes, and oils) of microscopic organisms (Waples, 1981). Fossil fuels contain the stored energy of sunlight that shone millions of years ago. The original organic molecules were processed into fuels after the sediments that contained them were buried in the Earth. For oil and natural gas, these source sediments are usually black shales or organic-rich carbonate rocks.

The map depicts the locations of many of Wyoming's oil and natural gas fields and the extent of oil shales. A few of the most important fields are named. With a few exceptions, all of Wyoming's oil and gas has been found in Paleozoic through Cenozoic sedimentary rocks. The oil and gas come from buried sedimentary rocks in the basins. As hydrocarbons are generated, they move into the nearest porous/permeable rock layers and flow up or laterally through the rock pores until they reach a permeability barrier (trap) of shale or other material through which oil cannot move easily. Usually, this pattern of accumulation is confined to areas in and near sedimentary basins.

Wyoming also has a huge deposit of oil shale in the Green River Basin. Organic material in the shale distills into a type of crude oil when heated. The price of oil is currently too low to make shale oil production profitable, but this resource may be utilized in the future.

A FEW FACTS ABOUT WYOMING'S OIL AND NATURAL GAS INDUSTRY (from VerPloeg, 1982; Basko, 1987; and DeBruin (in press).

- The first commercial use of oil in Wyoming was in 1851, when Jim Bridger and some of his friends mixed oil from a seep near present-day Casper with flour and sold it to emigrants for axel grease.
- The oldest field in Wyoming, Dallas Dome, was discovered in 1884 near an oil seep noted by Captain Benjamin Bonneville in 1833.
- Wyoming's biggest oil field is Salt Creek, discovered in 1889 and still producing. Cumulative production is approaching 700,000,000 barrels.
- Wyoming's biggest natural gas fields are Beaver Creek, discovered in 1938, and Whitney Canyon-Carter Creek, discovered in 1978. Cumulative production in each field is approaching 600 billion cubic feet.
- The most prolific oil-producing formations are the Pennsylvanian Tensleep Sandstone and the Pennsylvanian-Permian Minnelusa Formation.
- The most prolific natural gas-producing formations are the Mississippian Madison Limestone and the Jurrassic-Triassic Nugget Sandstone.
- There are over 900 fields producing from nearly 200 formations or combinations of formations.
- 21 of Wyoming's 23 counties produce oil or gas; currently, Teton and Platte Counties are not producers.
- In recent years, Wyoming's oil and gas industry has been the State's largest mineral industry in (1) value of materials produced, (2) income to the State, and (3) number of people employed.
- In addition to methane gas, carbon dioxide, helium, and sulfur (from hydrogen sulfide gas) are produced in Wyoming.

MAP EXPLANATION

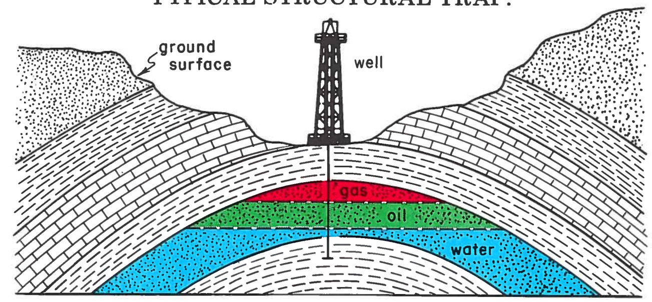
- Oil field
- Gas field

(Fields may produce both oil and gas—color represents dominant hydrocarbon.)

- Oil shale bearing rock
- Precambrian rocks
- Oil refinery

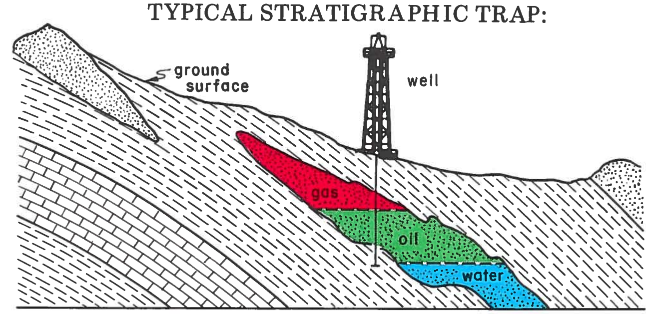
TWO WAYS TO TRAP OIL IN ROCKS

TYPICAL STRUCTURAL TRAP:



Anticline

TYPICAL STRATIGRAPHIC TRAP:

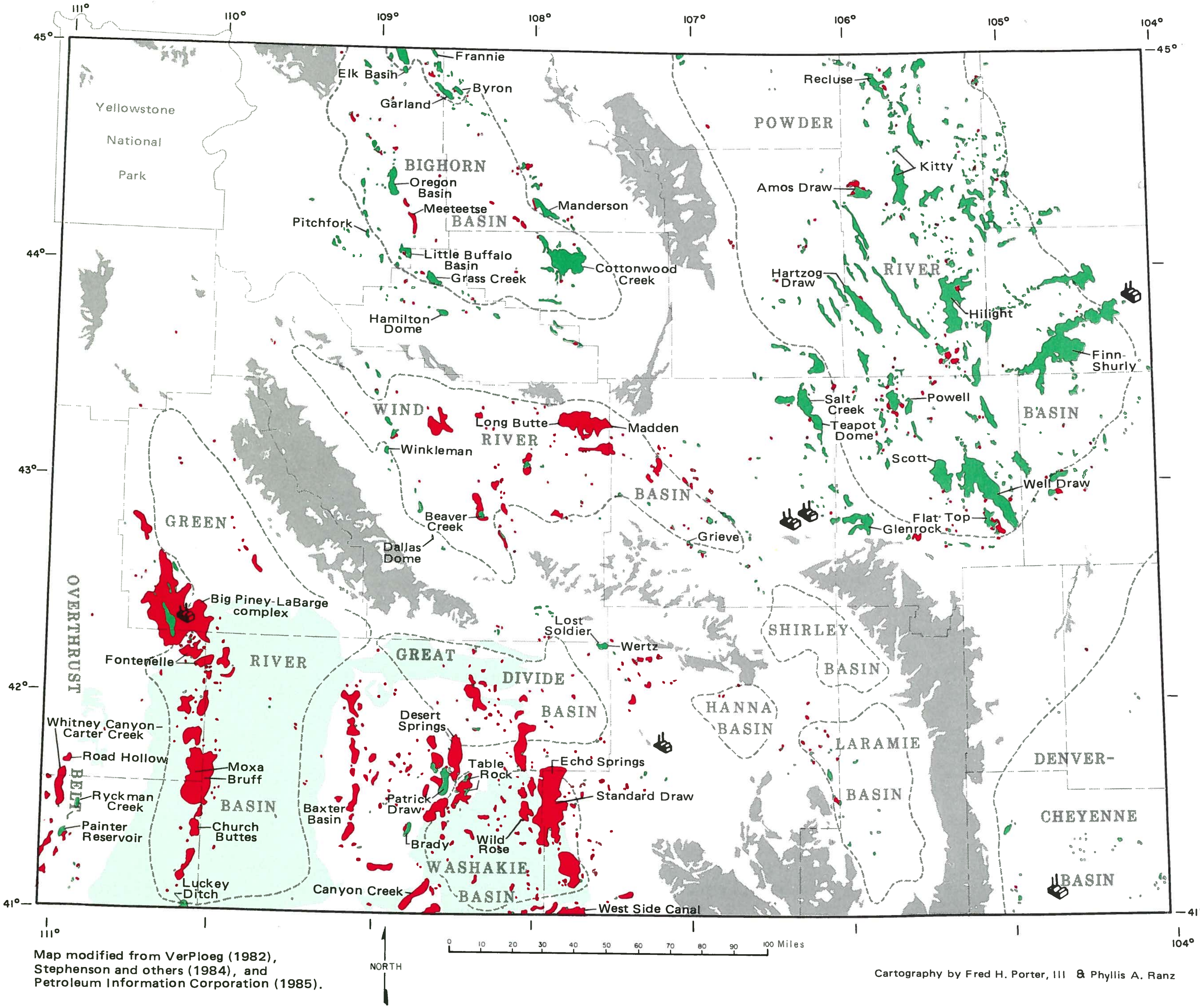


Tilted sedimentary rocks

EXPLANATION

- Porous/permeable sandstone (reservoir)
- Shale (possible source of oil)
- Limestone

Two common types of traps. In the structural trap, gas, oil, and water have separated out at the top of an anticline according to density. Structural traps characterize nearly all the older oil and gas fields in Wyoming, for example, fields rimming the Bighorn Basin. In many Overthrust Belt fields, structural traps are concealed under faulted sheets of rocks, making them very difficult to find. The other trapping mechanism is a stratigraphically controlled pinch out of the reservoir rock into less permeable rock. Many of the fields in the Powder River Basin are stratigraphic traps. Actually, many fields have both structural and stratigraphic elements. In addition, faults can be present as either conduits or permeability barriers.

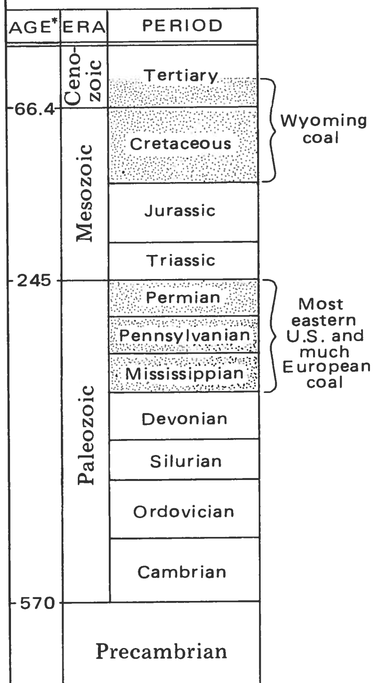


Map modified from VerPloeg (1982),
Stephenson and others (1984), and
Petroleum Information Corporation (1985).

Cartography by Fred H. Porter, III & Phyllis A. Ranz

COAL MAP OF WYOMING

WYOMING'S COAL IN GEOLOGIC TIME



*In millions of years (from Geological Society of America 1983 Geologic Time Scale).

MAP EXPLANATION

- Bituminous coal
- Subbituminous coal
- Lignite
- Strippable coal deposits
- Osage — Coal-fired electric generating plant

AGE: Early Cretaceous to Tertiary (Eocene).

ENVIRONMENT OF DEPOSITION: Most of Wyoming's Cretaceous coals originated as plants growing in peat swamps near the shifting margin of a salt-water sea that extended across North America from the Arctic Ocean to the Gulf of Mexico and sometimes covered most of the State. At the end of the Cretaceous, that sea retreated and Wyoming's basin-and-mountain topography began to form. Tertiary coals originated in the basins as thick layers of peat in swamps surrounding rivers and inland lakes.

MOST PROLIFIC FORMATIONS: Tertiary rocks of the Paleocene Fort Union Formation and Eocene Wasatch Formation.

BED THICKNESS: Cretaceous coal beds are usually less than 10 feet thick, but are occasionally 30 to 100 feet thick. Tertiary coal beds are commonly 30 to 80 feet thick and some beds exceed 200 feet. A coal bed over 100 feet thick is being mined in the Powder River Basin (Wyodak coal bed). Wyoming's Tertiary coals are among the thickest in the world.

RANK: Lignite to bituminous (see map for distribution).

EXTENT: Coal beds with less than 6,000 feet of overburden underlie more than 40,000 square miles of Wyoming (approximately 41 percent of the State). More than a trillion tons of coal resources may be present.

QUALITY: Ash and sulfur contents are characteristically low. Other important qualities like moisture and heat value vary with rank; moisture is lower and heat value is higher in higher ranked coals. Most of the coal mined in Wyoming is subbituminous, which is a low rank compared to coals mined in the eastern and midcontinental United States.

MINING: Today, nearly all (99 percent) of the coal mined in Wyoming is produced by surface-mining methods. Underground mining was more important in the past.

TRANSPORTATION: Wyoming coal is transported primarily by railroad (about 90 percent). Most of that coal travels on mile-long unit trains. Coal accounts for about 90 percent of the total rail freight tonnage originating in Wyoming.

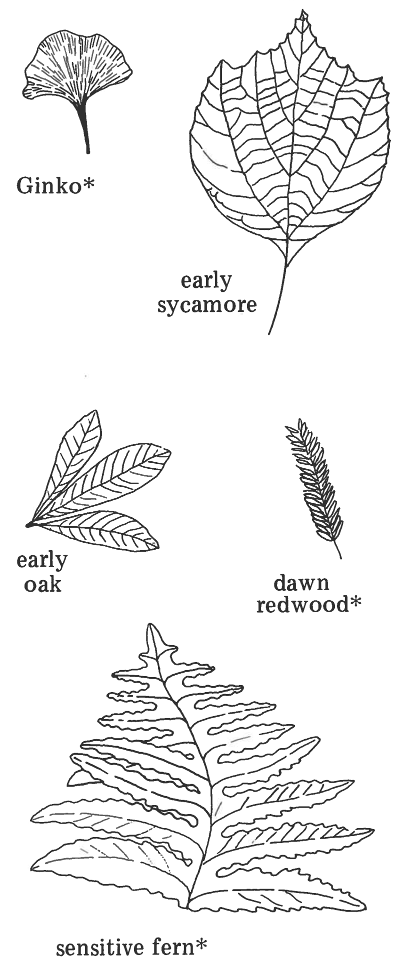
A FEW FACTS ABOUT WYOMING'S COAL INDUSTRY

- Wyoming is currently the second largest coal-producing state in the United states (behind Kentucky).
- Wyoming coal production has been over 140 million short tons each year since 1987, which is about 16 percent of the Nation's total.
- Surface mines in the Powder River Basin produce nearly 90 percent of Wyoming's coal.
- Approximately 85 percent of Wyoming's coal production is shipped out of state. Texas is the largest consumer.
- Approximately 98 percent of Wyoming coal is burned in coal-fired electrical generating plants, seven of which are in Wyoming (see map).

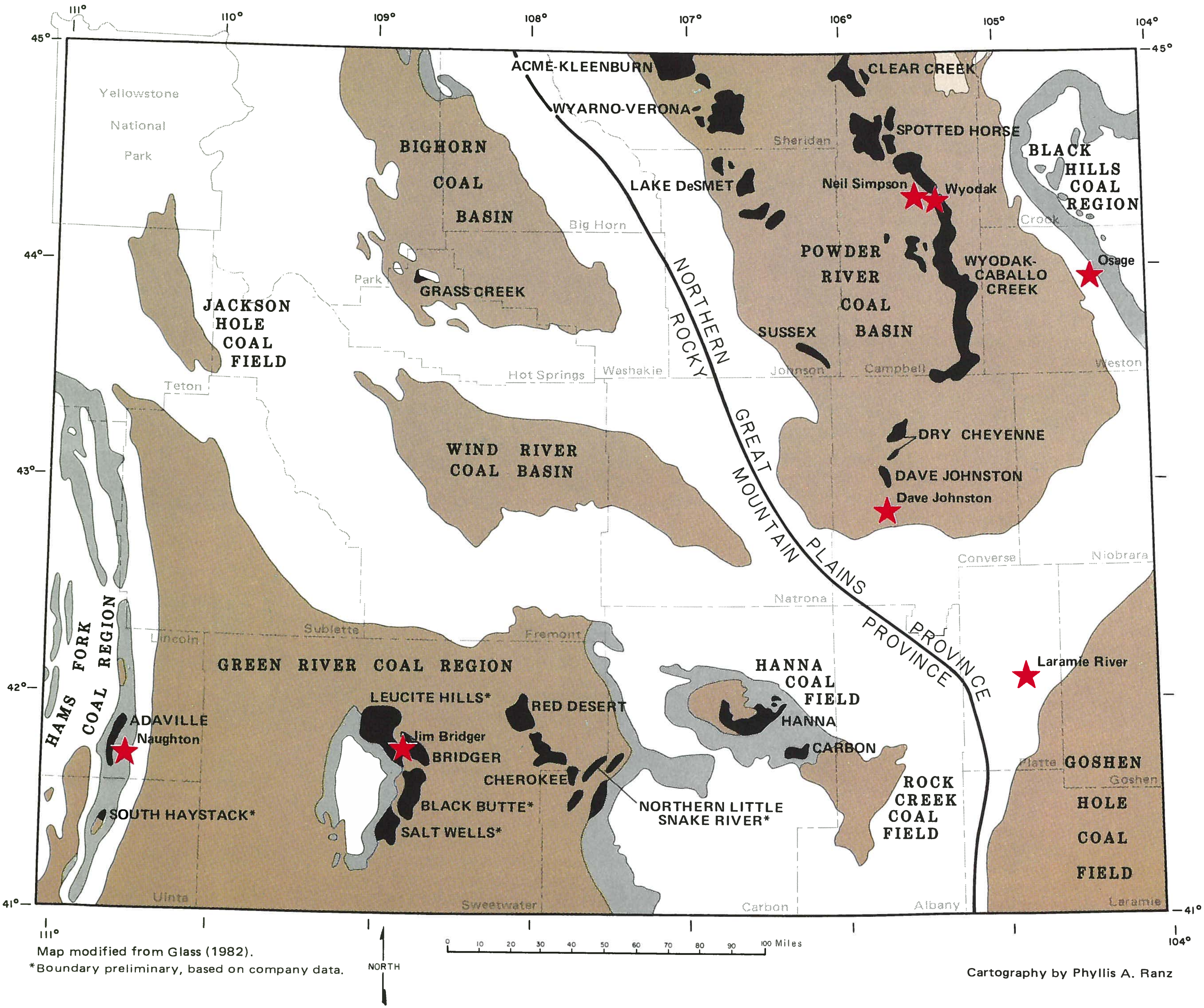
(Information from Glass, 1982; and Jones, 1988.)

SOME COMMON EARLY TERTIARY PLANTS FROM WYOMING'S COAL-BEARING FORT UNION FORMATION

(from Hickey and others, 1986)



*These species are still alive today, but not native to Wyoming.



Map modified from Glass (1982).
*Boundary preliminary, based on company data.

Cartography by Phyllis A. Ranz

INDUSTRIAL MINERALS, CONSTRUCTION MATERIALS, AND URANIUM MAP OF WYOMING

MAP EXPLANATION

INDUSTRIAL MINERALS AND CONSTRUCTION MATERIALS

- Trona
- Bentonite
- Clay, exclusive of bentonite
- Gypsum
- Decorative and ornamental stone (rock type or commercial name shown).
- Cement rock
- Sodium sulfate
- P Pigment (iron oxide)
- S Sulfur
- Z Zeolites
- x Selected sand and gravel quarries, exclusive of temporary Highway Department quarries.
- Selected crushed rock quarries, exclusive of temporary Highway Department quarries.
- Selected highway construction aggregate quarries.
- Processing plants (commodity shown).

URANIUM MINES AND DISTRICTS

- Uranium mines
- Districts having recent production (with district name).
- Districts having production before 1970 only (with district name).

ROCK UNITS

- Precambrian igneous and metamorphic rocks
- Cenozoic volcanic rocks
- Cenozoic intrusive rocks

This map combines uranium, trona, bentonite, and other mines with gravel pits, limestone quarries, and fertilizer processing plants, etc., to provide a view of Wyoming's diverse geologic resources not described on the other maps. Descriptions, occurrences, and origins of some of the most important items are discussed below, followed by some facts about the various industries.

Trona is a hydrated sodium bicarbonate/sodium carbonate. A huge deposit of trona in Sweetwater County formed during the Eocene at the bottom of an alkaline lake that experienced periodic evaporation. Deposits of trona and other evaporites formed in much the same way salts crystallize out of solution in the modern Great Salt Lake. At other times, this ancient Lake Gosiute experienced mass mortalities of fish, leaving the famous Green River fossil fish beds. Oil shale is another well-known product of this lake.

Gypsum, hydrated calcium sulfate, was also precipitated from evaporating waters, but gypsum deposits in Wyoming are much older than the trona beds and probably formed in shallow seas that covered parts of Wyoming in the Permian, Triassic, and Jurassic. Gypsum is commonly interbedded with red shale, siltstone, and sandstone.

Bentonite is a clay composed mostly of the mineral montmorillonite. It is an alteration product of volcanic ash and is usually found in Wyoming interbedded with Cretaceous marine shales.

Wyoming's major economic uranium deposits are in Paleocene and Eocene stream and alluvial fan sandstones. The uranium was concentrated by flowing ground water. The most important mineralization occurs in "roll fronts" at the contacts between oxidized and reduced host rocks.

A FEW FACTS ABOUT THESE INDUSTRIES

Industrial minerals

- Wyoming is the Nation's number one trona-producing state.
- The Green River Formation in the Green River Basin hosts the world's largest trona deposit, estimated at well over 100 billion tons. This area has the only large-scale underground trona mines in the world.
- Most of the trona mined in Wyoming is processed into soda ash and used to manufacture glass; it is also the primary component of baking soda and is used in paper, fertilizer, and detergent manufacturing, petroleum refining, and waste treatment.
- Wyoming is the Nation's number one bentonite-producing state. Bentonite is mined around the margins of the Black Hills uplift and in the Bighorn Basin.
- Some Wyoming bentonite swells up to 15 times its original volume when it is wetted, a property that makes it useful as an oil well drilling mud, as a sealant in water-containment ponds, and as a binder for foundry sands and pelletizing taconite (an iron ore). It is also used in the manufacture of cosmetics, soaps, and paper.
- Gypsum is mined by surface methods in the Bighorn Basin and west of Laramie. It is used to make wallboard and mixed with limestone for cement.
- Wyoming limestone is used to control power plant emissions, to make cement, and has been mined for sugar beet refining.
- Phosphate mined in Utah is converted to fertilizer at a plant near Rock Springs, Wyoming. Phosphate occurs in western Wyoming in the Permian Phosphoria Formation, but it is not mined there.
- Several zeolite resources have been identified in tuffaceous volcanic and sedimentary rocks in Wyoming, but only a few have been mined. Zeolites are highly absorbent and are used in water softeners and in the manufacture of catalysts of oil refining, etc.
- Sulfur, has been mined in Wyoming near Thermopolis, Cody, and Auburn. Sulfur is also produced from high-sulfur natural gas.

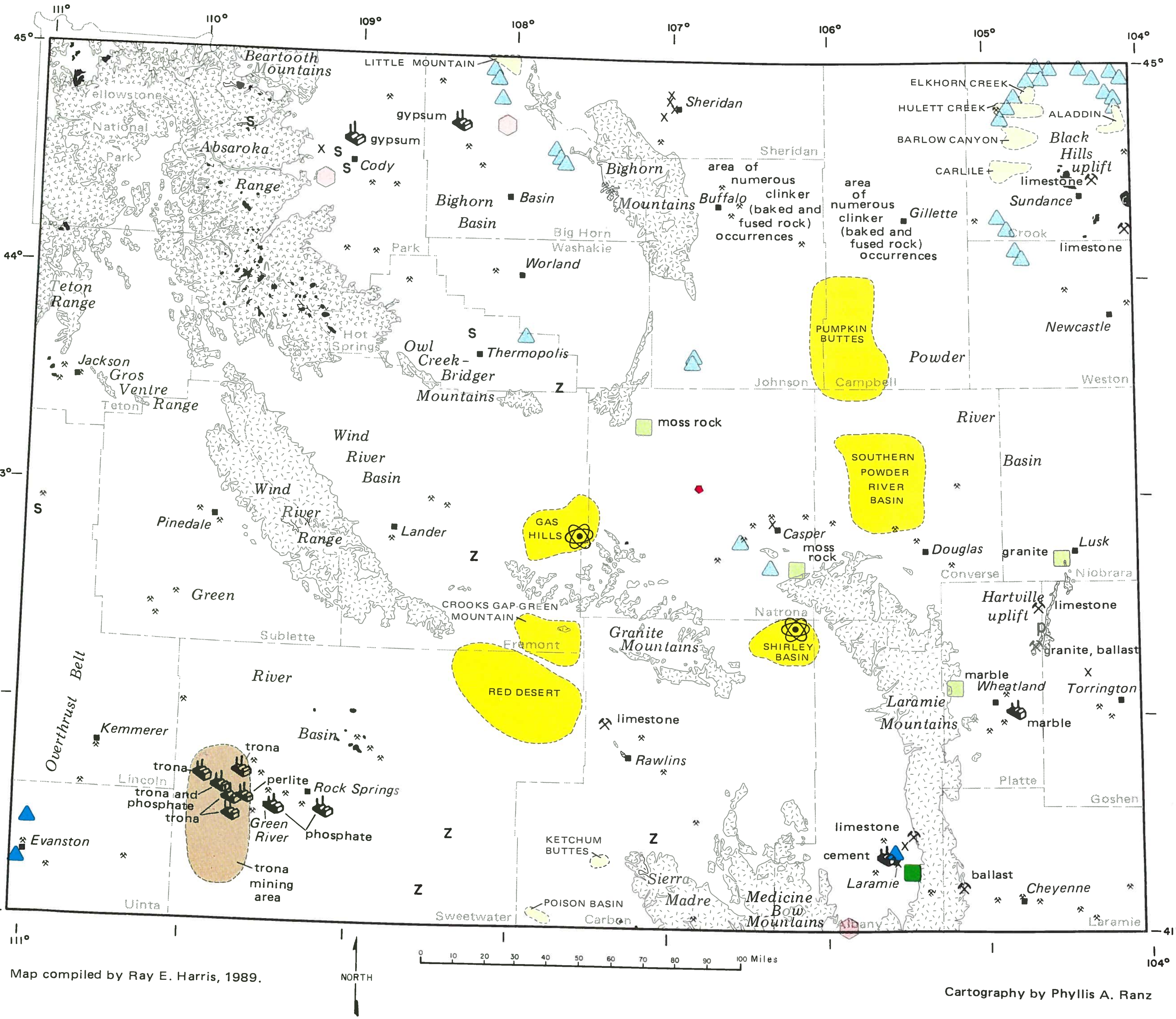
Construction materials

- 4 to 5 million tons of sand, gravel, crushed rock, railroad ballast, and other construction materials are produced in Wyoming each year.
- Decorative and ornamental stones mined in Wyoming include marble, clinker (baked and fused rock), granite, quartz, sandstone, "moss rock," and limestone.

Uranium

- Wyoming has the second largest uranium resource in the United States.
- Uranium was first mined in Wyoming in 1918. The first important uranium mining in Wyoming began in the 1950s, when new discoveries in Tertiary sedimentary deposits were exploited to satisfy a high demand by the weapons industry. A larger growth period occurred in the late 1960s and 1970s, as a response to demand from the nuclear power industry. This demand shrank after 1980.
- Most Wyoming uranium production has been from open pit or underground mines; *in situ* solution extraction has become more important recently.

(Information from Culbertson, 1986; Harris, 1985a, 1985b, 1989; Harris and King, 1986; and Hausel, 1986.)



Map compiled by Ray E. Harris, 1989.

Cartography by Phyllis A. Ranz

METALS, PRECIOUS STONES, AND SEMIPRECIOUS STONES MAP OF WYOMING

MAP EXPLANATION

MINERALIZED AREAS AND OCCURRENCES

Metals

- Gold
- Gold and platinum
- Gold and tin
- Iron
- Copper, silver, and gold
- Copper, silver, and zinc
- Lead, silver, and zinc
- Manganese
- Tungsten
- Rare earth metals

Precious and semiprecious stones

- Diamonds
- Jade
- Beryl
- Rubies and sapphires
- Agates and (or) petrified wood

ROCK UNITS

- Precambrian igneous and metamorphic rocks
- Cenozoic volcanic rocks
- Cenozoic intrusive rocks

Considering Wyoming's varied geological history, it is not surprising that the State inherited diverse and complicated deposits of metals and precious and semiprecious stones. The map below displays locations of past or present commercial development and also significant occurrences that have not yet been mined.

To date, Wyoming's most successful metals industry has been mining of iron ore. Mines near Hartville, in the Hartville uplift of eastern Wyoming, began producing copper about a hundred years ago, but quickly shifted from copper to iron, which was mined until 1981. The Atlantic City mine, in the southern Wind River Range, was active from 1962 until 1983. Much ore remains in these areas. In both cases, the iron deposits occur in early Precambrian metamorphic rocks. At Hartville, the ore is massive and specular hematite, while in the Wind River Range the ore is primarily banded magnetite/chert iron formation.

Copper mineralization has been found in a wide variety of ages and types of rocks in Wyoming, from Precambrian metamorphics, to Paleozoic sedimentary rocks, to Cenozoic igneous rocks. For a short time around the turn of the century, a copper mining and smelting industry flourished at Grand Encampment in the Sierra Madre. Giant copper deposits containing millions of tons of low-grade copper with molybdenum, zinc, lead, gold, silver, and titanium have been identified in the Absaroka Mountains.

Gold deposits in Wyoming range in age from Archean to Recent. Gold and associated metals are found in veins and shear zones, disseminated in igneous or metamorphic rocks, and in recent and ancient placers. The precious metal occurs in association with several other types of deposits around the state, most commonly copper.

Jade is Wyoming's official gemstone. Wyoming jade is composed of the amphibole mineral, nephrite (the other jade mineral is the pyroxene, jadeite). It has been found as veins and pods in its Precambrian source rocks in the Granite Mountains and as boulders in stream deposits throughout a large area of central Wyoming. The most valuable Wyoming jade is light green and transluscent; color varies from light green to black. Small occurrences of rubies and sapphires are sometimes associated with or found near the jade deposits.

Petrified wood and agates are fairly common across wide areas of Wyoming. Collectors find several varieties of agate (cryptocrystalline quartz), including banded and moss agate, jasper, and *Goniobasis* agate (full of agatized high-spired snail shells). Most of Wyoming's petrified wood formed from trees buried by volcanic ash in the middle Tertiary. Silica in the ash gradually replaced the woody material.

In 1975, diamonds were discovered in Devonian igneous rocks (kimberlite diatremes) intruding Precambrian granite in the southern Laramie Mountains. This was very intriguing because many of the world's diamond deposits are found in kimberlite, a relatively rare rock type. The diamonds were brought up by the kimberlite magma from more than 120 miles below the surface, where pressures and temperatures are high enough to form diamonds. Although there are currently no operating diamond mines in Wyoming, companies continue to explore the area. Both gem-quality and industrial-quality diamonds have been recovered.

A FEW FACTS ABOUT THESE INDUSTRIES

Metals

- More than 150 million tons of iron ore have been mined in Wyoming.
- Around 20 million pounds of copper were mined from Precambrian rocks at the Ferris-Haggarty mine and other mines in the Grand Encampment district of the Sierra Madre between 1881 and 1908.
- The first reported gold discovery in Wyoming was in the southern Wind River Range in 1842.
- The most important gold mining area is the historic South Pass region in the southern Wind River Range (first discovered in 1867). An estimated 327,000 ounces of gold have been recovered from mines in this area.

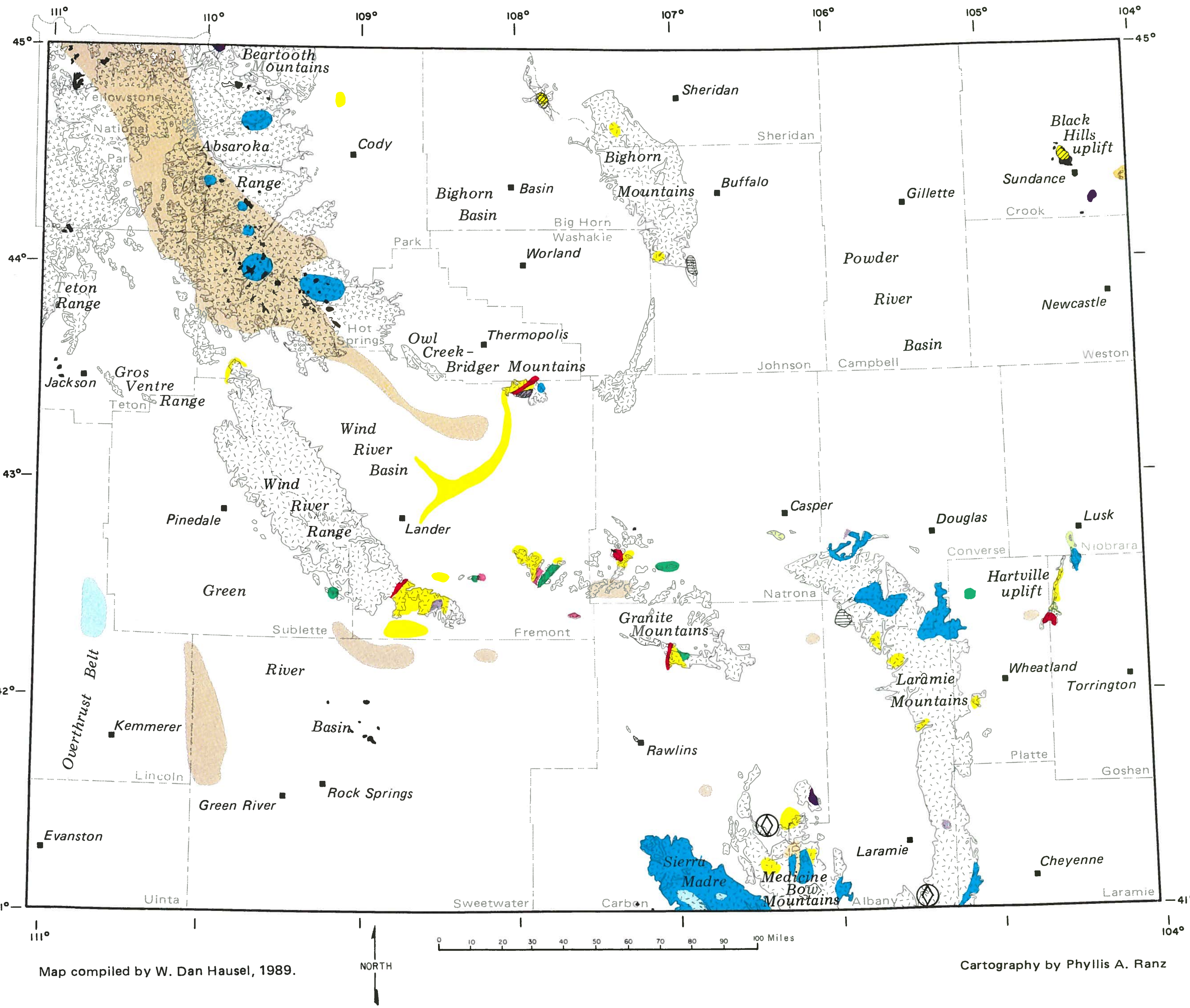
Precious stones

- Jade was first discovered in Wyoming along the Sweetwater River in the mid 1930s.
- The largest light green jade boulder ever found in Wyoming weighed 3,200 pounds. A 14,000-pound boulder of black jade was discovered in Sublette County in the 1970s.
- The largest gem-quality diamond found in Wyoming weighed 0.86 carat.

Semiprecious stones

- In addition to agates and petrified wood shown on the map, collectors find quartz crystals, fluorite, collectable specimens of many ore minerals, and other rocks and minerals in Wyoming.

(Information from Hausel, 1982, 1986, 1989, personal communication, 1989; and Osterwald and others, 1966.)



Map compiled by W. Dan Hausel, 1989.

Cartography by Phyllis A. Ranz

ICE AGE (PLEISTOCENE EPOCH) FEATURES OF WYOMING

The Ice Age (Pleistocene Epoch) ended only about 10,000 years ago, a few thousand years after the first humans wandered into Wyoming, perhaps in search of Pleistocene game animals. At least three major glacial episodes, starting around 1,600,000 years ago, left their marks on the Wyoming landscape. Because these events were so recent, geologically speaking, the traces are still easy to observe in many places.

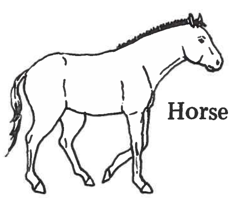
The huge continental ice sheet that spread its frozen blanket over most of Canada, Alaska, and the northernmost United States never reached Wyoming. However, separate local glaciers did form in the State. The map shows the approximate maximum extent of the Late Pleistocene glaciers in Wyoming. In a large area of northwest Wyoming, an ice sheet covered everything but the highest peaks. Elsewhere, alpine glaciers formed in the high mountainous areas and spread down stream valleys onto the edges of the basins, where they were stopped by more rapid melting at the lower elevations. Glacial deposits are the record of these ice conveyer belts that picked rocks off the high mountains and valleys, flowed downhill cutting U-shaped valleys, and deposited their debris in lumpy melting heaps of unsorted sediments (moraines) that mark where the ice stopped and retreated.

At times, Wyoming basins were very cold, arid, and windy. Sand dunes that formed then are mostly covered with thin vegetation today but some, like parts of the Ferris and Killpecker Dunes, are still bare and actively moving. There are also some thick layers of wind-deposited dust (called loess). Winds actually scopped out hollows in some of the basin floors; the biggest of these is the Big Hollow west of Laramie (9 miles long by 3 miles wide).

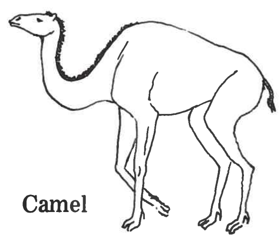
During some of the colder episodes of the Pleistocene, permafrost (permanently frozen ground) developed across much of Wyoming. Repeated freezing and partial thawing created cracks in the frozen ground that, after many repetitions, made wedges of ice like those seen today in northern Alaska. In Wyoming, the permafrost is gone but the former ice wedges, now filled with sand or dirt, have been identified in places like pipeline trenches and earth-fill dumps, where excavations expose them (periglacial wedges on the map).

Some caves in Wyoming began forming during the Ice Age, and many existing ones were enlarged then. The enormous erosive activity of glaciers exposed soluble rocks like limestone, and locally the increased precipitation or melt water increased the rate of rock dissolution that forms caves. Karst topography, including sink holes like The Sinks west of Lander, are at least partly Pleistocene features.

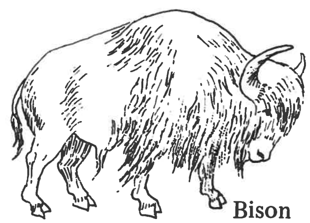
Many Ice Age animals would be familiar to us today, but others would not. Mastodons, mammoths, horses, and camels are among the species that mysteriously disappeared from North America at the end of the Ice Age. Their bones have been found at many sites in Wyoming. Toward the end of the Pleistocene, humans arrived in Wyoming, leaving stone implements and other evidence of their occupation at the sites shown on the map.



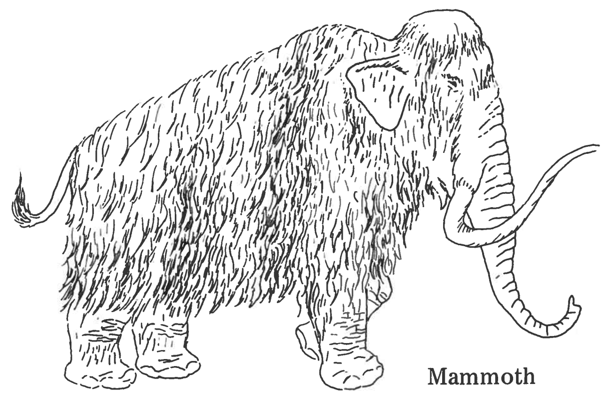
Horse



Camel



Bison



Mammoth

Glacial deposits — including various types of moraines and associated outwash deposits (modified from Love and Christiansen, 1985).

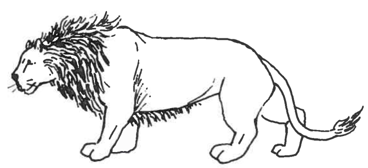
Sand dunes and loess — (modified from Love and Christiansen, 1985).

v Periglacial wedges — (from Mears, 1987).

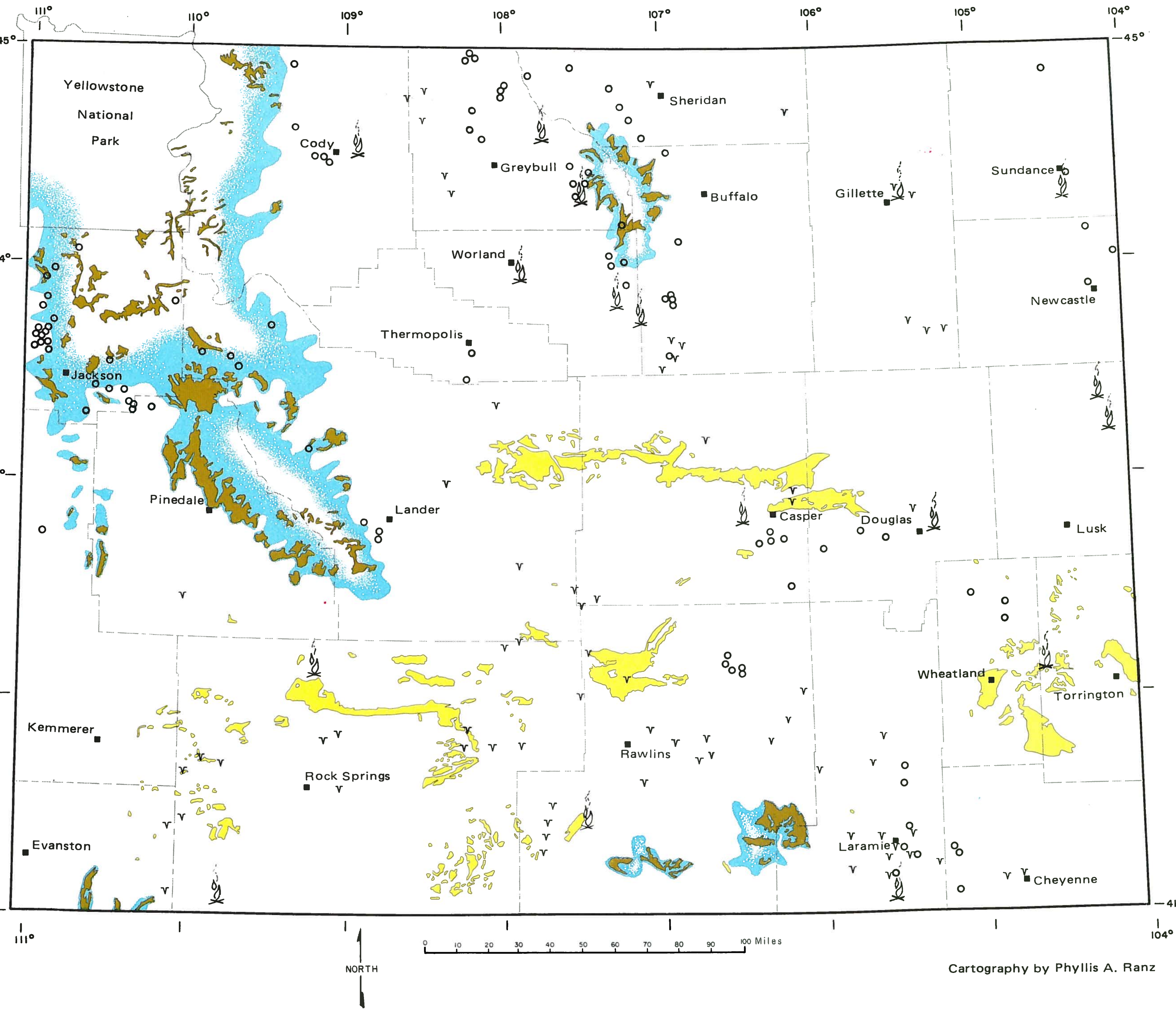
o Caves and karst — (localities from Hill and others, 1976; and Wayne Sutherland, personal communication, 1988).

Approximate maximum extent of Late Pleistocene glaciation — glacial moraines within this boundary include deposits of later, less extensive, glacial stillstands (compiled by Brainerd Mears, Jr., 1988).

Human occupation sites dating from the Late Pleistocene — most are between 10,000 and 12,000 years old (Walker, 1987, and personal communication, 1988).



American lion



Cartography by Phyllis A. Ranz

SURFACE WATER AND PRECIPITATION MAP OF WYOMING

Although much of Wyoming is semiarid, several major rivers have their headwaters in mountainous areas of the State and Wyoming exports water for use by neighboring states. This surface water and precipitation map shows the average annual amount of precipitation for Wyoming, the patterns of rivers that transport it, and the location of reservoirs and lakes that impound it. Geology plays an important role in determining (1) where precipitation falls, (2) the course of streams and rivers, (3) the locations of lakes and reservoirs, and (4) the movement of ground water (not discussed here).

The geologic structures and different erodabilities of rocks and sediments that streams and rivers flow across influence the paths taken by the water. The porosity and permeability of underlying rocks partially determine the percentage of precipitation that seeps into the ground versus that which flows on top. Soil development and vegetation also influence the amount and pattern of surface-water flow.

The map shows average precipitation in Wyoming for the 29-year period 1951 to 1980, taken from daily measurements made at about 140 stations around the state (Martner, 1986). Mountain values are estimates because there are too few actual stations. Wyoming's average annual precipitation varies in different places from about 6 inches to about 60 inches, with the lowest figures in the Great Divide Basin and north-central Bighorn Basin and the highest in northwestern Wyoming mountain ranges. Rainfall patterns are largely controlled by the mountain-basin topography of the State. Wyoming's mountain ranges capture most of the precipitation because they force air to rise, cooling it and causing condensation of moisture. Basins are drier because condensation is inhibited as air descends from the mountains and warms up. Rain shadows develop downwind of mountains (compare Jackson Hole and the Teton Mountains).

When a drop of water or a flake of snow falls in Wyoming, it could be headed for a long voyage to one of two oceans or a shorter trip to the Great Salt Lake or the Great Divide Basin, which have no outlet rivers or streams. This map shows the complex patterns that divide the state into five major drainages determined by the final destinations of the transported surface water:

I. **GREAT DIVIDE BASIN.** The small amount of precipitation that falls in this basin may flow into intermittant streams or pond into low spots, but it does not leave the basin in streams or rivers. The Continental Divide simply splits around this arid region and leaves the water to seep into the ground or evaporate.

II. **GREATER GREEN RIVER BASIN.** Most of the surface water of southwestern Wyoming finds its way to the Green River, which flows into the Colorado River in southern Utah. What is left of the Colorado water, after it is exploited by a series of dams and irrigation projects, flows into the Gulf of Mexico and ultimately the open Pacific Ocean.

III. **BEAR RIVER.** This river drains a narrow strip of western Wyoming and flows into the north end of the Great Salt Lake, which, at its present size, has no outlet to an ocean. The Bear River transports Wyoming's contribution to the salt and other mineral content of the Great Salt Lake.

IV. **SNAKE RIVER.** This river carries water from the scenic Teton and Gros Ventre Ranges and vicinity on a northern route to the Columbia River and Pacific Ocean. It drains one of the wettest areas of the State.

V. **MISSOURI RIVER COMPLEX.** Over two thirds of the land area of the state is drained by a series of rivers that meet the Missouri River in states bordering Wyoming on the north and east. From there, the water merges into the Mississippi River, the Gulf of Mexico, and finally the open Atlantic Ocean. Before Pleistocene glaciers forced the Missouri into its present southern route, it drained north into Hudson Bay.

On the map, this area of Wyoming is divided into four major subdivisions (long dashes) and a few minor subdivisions (short dashes). (A) the Gallatin and Madison Rivers, with headwaters in Yellowstone National Park, flow north to Three Forks, Montana, and meet to form the Missouri River. (B) All the rivers in this big area of northern and central Wyoming meet the Yellowstone River in Montana before it flows into the Missouri. (C) Several rivers originating in northeastern Wyoming meet the Missouri in North and South Dakota and Nebraska. (D) The North Platte River originates in Wyoming and is dammed by five reservoirs before it reaches Nebraska. Water in the extreme southeastern corner of Wyoming flows to the South Platte River in Colorado. The two Plattes meet in Nebraska and then join the Missouri-Mississippi system.

MAP EXPLANATION

Precipitation, in inches per year. Contour interval = 2 inches, except in some mountainous regions where the intervals are 10 to 20 inches.

River or stream. Most important rivers are labeled. Dashed lines indicate intermittent streams.

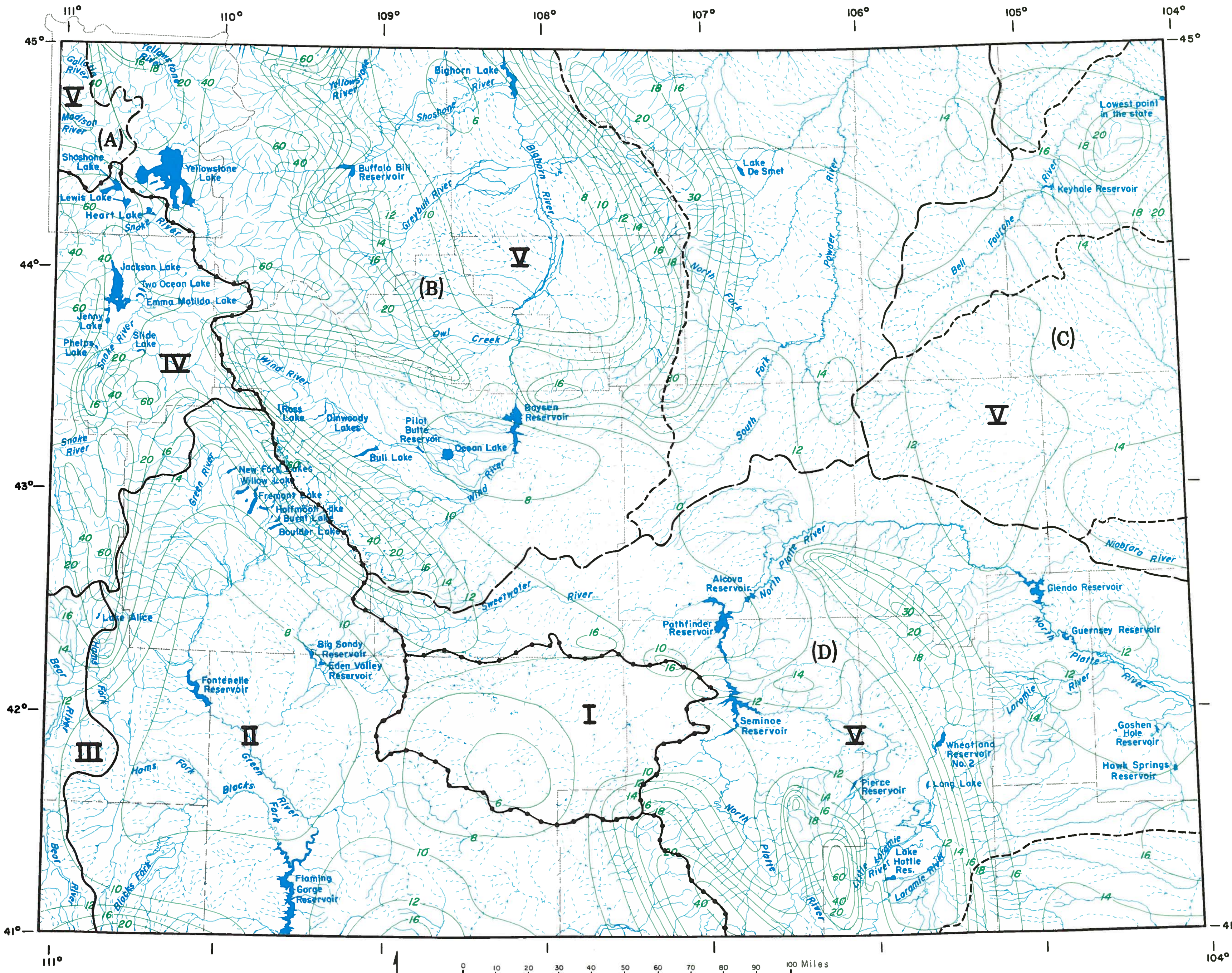
Lake or reservoir. Straight line across emerging drainage indicates dam site.

Continental Divide

Major drainage division boundary. Roman numeral refers to description in text.

First-order subdivision of the Missouri River complex, capital letters refer to descriptions in the text.

Second-order subdivision of the Missouri River complex.



Precipitation data from Martner (1986).

Cartography by Phyllis A. Ranz

SOIL ASSOCIATIONS MAP OF WYOMING

MAP EXPLANATION

SOILS OF THE MOUNTAINS AND MOUNTAIN VALLEYS.
Dark and light colored soils of the high mountains that are usually moist. AAP[1] of 18-40 inches (45-100 cm) and MSST[2] of less than 59°F (15°C).

- **1.** Soils formed from residual materials, colluvium, and glacial deposits.
- **2.** Soils formed from alluvium and other transported materials.

Dominantly dark colored soils of mountains and mountain valleys formed from residual materials. AAP of 14-24 inches (35-60 cm), MAST of less than 47°F (8°C), and MSST of more than 59°F (15°C).

- **3.** Usually moist in some parts during the summer.
- **4.** Usually dry during the summer.

SOILS OF THE INTERMOUNTAIN BASINS AND FOOTHILLS.
Dominantly light colored soils of basins, terraces, and fans; usually dry or may be moist in some parts during the summer. AAP of 8-14 inches (20-35 cm), MAST of less than 47°F (8°C), and MSST of more than 59°F (15°C).

- **5.** Soils formed from residual materials.
- **6.** Soils formed from transported materials.

Dominantly light colored soils of basins, terraces, and fans; usually dry in all parts. AAP of less than 10 inches (25 cm), MAST of 47-59°F (8-15°C) and MSST of more than 59°F (15°C). Includes some soils in the southwest corner of Wyoming with AAP of 8-14 inches (20-35 cm), MAST of less than 47°F (8°C), and MSST of more than 59°F (15°C).

- **7.** Soils formed from residual materials.
- **8.** Soils formed from transported materials.

SOILS OF THE EASTERN WYOMING PLAINS.
Dark and light colored soils on upland plains, terraces, and fans; usually moist in some parts during the summer. AAP of 12-16 inches (30-40 cm), MAST of 47-59°F (8-15°C) and MSST of more than 59°F (15°C).

- **9.** Soils formed from residual materials on steep uplands.
- **10.** Soils formed from transported materials.
- **11.** Soils on nearly level to rolling upland plains, terraces, and fans.

[1]AAP = Average annual precipitation
[2]MSST = Mean summer soil temperature at 50 meters depth.
[3]MAST = Mean annual soil temperature

Soils form at the interface between the rock crust of the Earth and the atmosphere, where bedrock, climate, vegetation, and topography interact to produce a mixture of rock particles and other mineral matter, organic material, and moisture. Soil is one of our most valuable and most easily disturbed Earth resources. There are far too many different types of soil (and different classification schemes) to show on a map of this scale. Therefore, this map delineates general areas where bedrock, vegetation, climate, and topography are similar and the resulting soils share some similarities. The map units thus designate soil associations, not soils.

There are three major divisions: mountains and mountain valleys, intermountain basins and foothills, and eastern Wyoming plains. Within these divisions, soil associations are separated on the basis of climatic factors and on whether they formed directly over a bedrock outcrop (residual soils) or over transported mineral matter. These smaller units can be grouped for discussion:

<u>Units 1 and 2</u>
—Steep to very steep mountainous landscapes and some mountain-bound valleys (elevations 5,000 to 13,000+ feet).
—Cold winters and cool summers with wide temperature fluctuations possible in all seasons.
—Residual soils primarily on metamorphic and igneous rocks, transported soil materials include stream and glacial sediments.
—Dominantly conifer forests or grass-shrub.
—Major land uses are recreational, wildlife habitat, grazing, some timber harvesting.

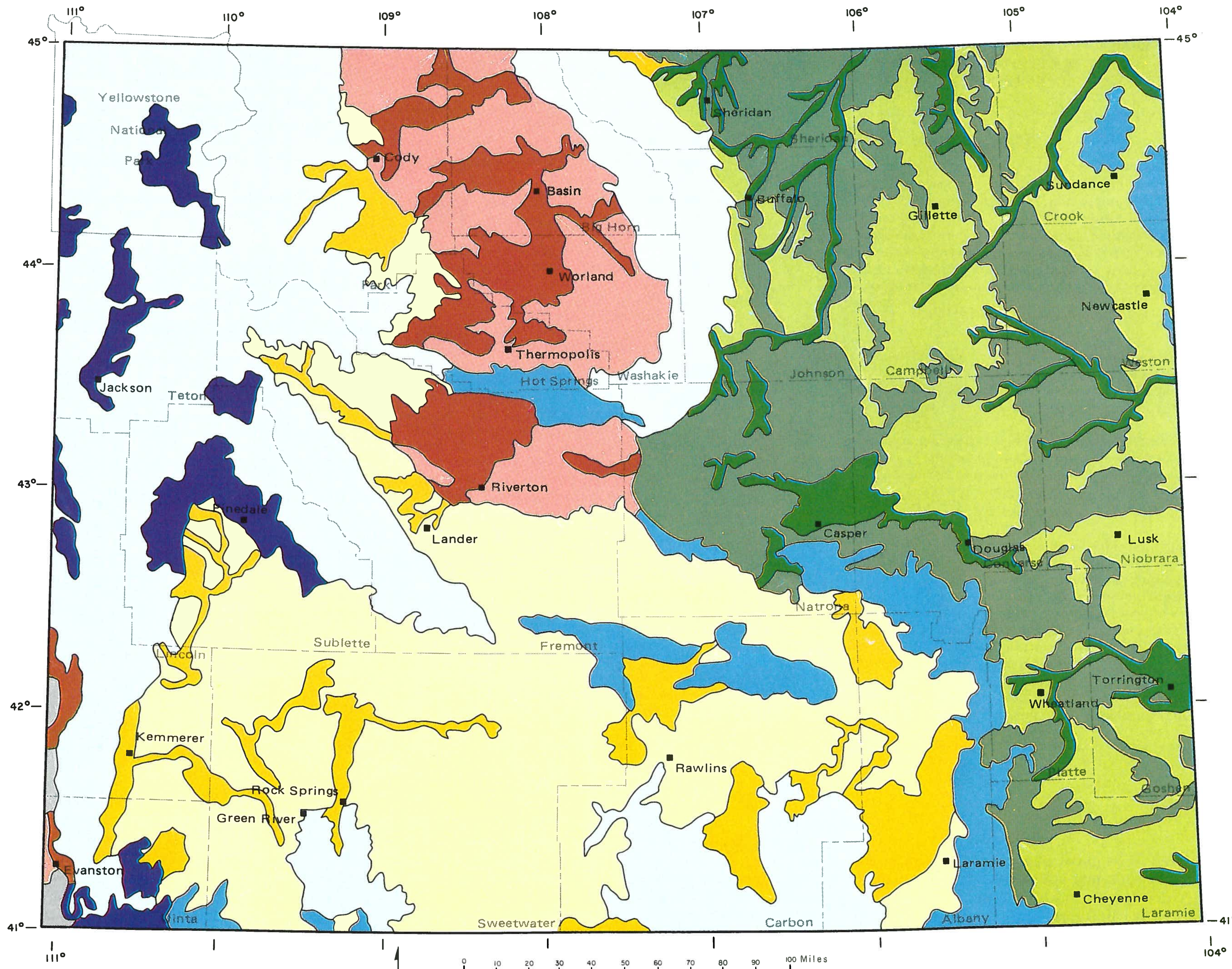
<u>Unit 3</u>
—Rolling to steep mountainous landscapes with narrow to broad valleys (elevations 4,000 to 10,000+ feet).
—Warmer than the high mountains, but cooler than plains and basins.
—Residual soils on igneous, metamorphic, and sedimentary rocks; transported soil materials mostly locally derived alluvium.
—Conifer woodland and grass-shrub rangeland.
—Major land uses are livestock grazing, wildlife habitat, some timber harvesting.

<u>Unit 4</u>
—Rolling to very steep mountainous landscapes (elevations 6,500 to 7,500 feet).
—Cold winters and cool dry summers with wide temperature variations.
—Residual soils mostly on the Tertiary Wasatch Formation.
—Grass-shrub with scattered juniper and cottonwood along drainages.
—Major land uses are livestock grazing, wildlife habitat.

<u>Units 5 and 6</u>
—Basins and mountain foothills (elevations 5,000 to 8,000 feet).
—Cold dry winters and hot dry summers.
—Residual soils on sedimentary rocks, mostly clay shale, sandstone, siltstone, and limestone; transported soil materials include alluvial deposits along major streams and windblown sand and dust.
—Bunch grass-shrub, sparse in central basins and denser along foothills.
—Major land uses are livestock grazing and wildlife habitat; irrigated land primarily grows hay.

<u>Units 7 and 8</u>
—Nearly level floodplains and terraces and rolling alluvial fans and uplands (elevations 3,500 to 7,000 feet).
—Cold winters and cool to hot dry summers.
—Residual soils on mostly horizontally bedded sedimentary rocks; transported soil material is primarily alluvium from local sources.
—Bunch grass-shrub, scattered juniper on upland breaks, some wet meadow bottom land grasses and sedges.
—Major land uses are grazing, hay land, and some important irrigated cropland.

<u>Units 9, 10, 11</u>
—Rolling plains with steeper areas near streams and mountains (elevations 3,000 to 7,000 feet)
—Wide temperature fluctuations, semiarid.
—Residual soils on tilted or flat sedimentary rocks, transported soil materials primarily river alluvium.
—Short and mid grasses, with tall grasses in areas of higher precipitation, scattered areas of ponderosa pine.
—Major land use is grazing, some areas of irrigated cropland.



Map and text information modified from Soil Conservation Service (1977).

Cartography by Betty S. Wills and Phyllis A. Ranz

VEGETATION MAP OF WYOMING

Although some geologists regard vegetation as the troublesome material that covers rocks, others have found ways to use its variations as indicators for mapping soils, rocks, and even the presence of different trace elements. The vegetation of any area is a complex and sensitive response to many Earth-related factors including soil and rock substrate, precipitation, temperature, drainage, slope, wind, and sun exposure.

This map shows the approximate locations of some major divisions of Wyoming's natural vegetation. The vegetation in many areas of Wyoming has not been greatly affected by human activities; the basic natural patterns still persist over large regions. In general, forests, other woodlands, and savannas are associated with mountains and foothills; alpine tundra with the highest mountain areas; grasslands with the Great Plains of eastern Wyoming and some foothills areas; and sagebrush, greasewood, and other dry-land shrubs with most of the State's intermountain basins.

Because of the map scale, two major natural vegetation types are not shown: (1) the narrow strips of cottonwoods, willows, shrubs, and grasses that grow along rivers and streams and (2) grasslands and shrublands that comprise the foothills fringing mountain forests and woodlands. Cultivated land is also not shown.

MAP EXPLANATION

1 = Description 2 = Occurrence

SHRUBLANDS, GRASSLANDS, AND OTHER NONFORESTED VEGETATION

ALPINE TUNDRA

1. A mosaic of herbaceous vegetation dominated by alpine avens, alpine bistort, alpine forget-me-not, alpine timothy, and other grasses, sedges, and herbs. Trees, if present, are usually short and wind-pruned (krummholz), and include spruce, fir, and pine. Willow thickets occur in depressions, and cushion plants grow close to the soil surface on windy sites with little snow accumulation.
2. Above tree line.

SAND DUNES

1. Unstabilized to partially stabilized sand dunes with sparse herbaceous vegetation. Indian rice grass, prairie sandreed, scurfpea, rabbitbrush, and other grasses, herbs, and shrubs are common
2. Intermountain basins and eastern grasslands. The most extensive dunes occur northeast of Rock Springs, southeast of the Ferris Mountains (north of Rawlins), and northeast of Casper.

SAGEBRUSH STEPPE

1. Shrubland dominated by big sagebrush, with associates that may include western wheatgrass, bluebunch wheatgrass, needle-and-thread grass, blue grama, Sandberg bluegrass, junegrass, rabbitbrush, fringed sage, and other grasses, herbs, and shrubs. Black sagebrush may dominate on shallower soils, and silver sagebrush may dominate in moister habitats.
2. Throughout the intermountain basins and in the lower foothills, usually on nonsaline soils; often occurs in a mosaic with desert shrublands.

DESERT SHRUBLANDS

1. Shrublands dominated by greasewood, Gardner saltbush, shadscale, birdfoot sagebrush, bud sage, and/or big sagebrush.
2. Lower elevations, especially in the intermountain basins where annual precipitation is low; often on saline soils. Greasewood is characteristic of low depressions and streamsides where water accumulates during the spring. Occurs as a mosaic with sagebrush steppe.

MIXED-GRASS PRAIRIE

1. Grasslands dominated by blue grama, western wheatgrass, junegrass, Sandberg bluegrass, needle-and-thread grass, rabbitbrush, fringed sage, and various herbs, shrubs, and other grasses. Small tracts of shortgrass prairie with buffalo grass occur in southeast Wyoming.
2. Eastern Wyoming on the western Great Plains and in parts of the Laramie and Shirley Basins.

WOODLAND AND FOREST VEGETATION

JUNIPER WOODLAND

1. Open woodlands dominated by Rocky Mountain juniper in eastern Wyoming and Utah juniper in the west. Common associates may include limber pine, ponderosa pine, sagebrush, mountain mahogany, and bluebunch wheatgrass. Pinyon pine occurs with Utah juniper in a small area by Flaming Gorge Reservoir.
2. Foothills or escarpments with rocky or shallow soils. Most common in the western intermountain basins and adjacent foothills.

OAK WOODLAND

1. Woodlands dominated by bur oak in the Black Hills and by Gambel oak in the southwestern foothills of the Sierra Madre.
2. Small areas in the northern Black Hills and on the west slope of the Sierra Madre.

PONDEROSA PINE FORESTS, WOODLANDS, AND SAVANNAS

1. Dense forests to open woodlands or savannas dominated by ponderosa pine, with an understory of grasses, herbs, and shrubs. Limber pine and Douglas fir are common associates in the Bighorn and Laramie Mountains; white spruce and aspen are common associates in the Black Hills.
2. Lower elevations and foothills on north and east slopes of the Bighorn and Laramie Mountains, escarpments in the Powder River Basin and the eastern plains, and throughout the Black Hills and Bearlodge Mountains. Often interspersed with foothill grasslands.

SPRUCE-FIR FOREST

1. Subalpine forests dominated by Engelmann spruce and subalpine fir. Common associates include lodgepole pine, limber pine, aspen, and, in northwest Wyoming, whitebark pine. Understory plants include dwarf huckleberry and other grasses, herbs, and low shrubs. Often interspersed with aspen groves, lodgepole pine forest, or mountain meadows, and with Douglas fir at lower elevations.
2. Higher elevations of most major mountain ranges, extending up to alpine treeline. Sometimes found on moist north slopes or in ravines at lower elevations. Often occurs in a mosaic with subalpine meadows and alpine tundra.

DOUGLAS FIR FORESTS AND WOODLANDS

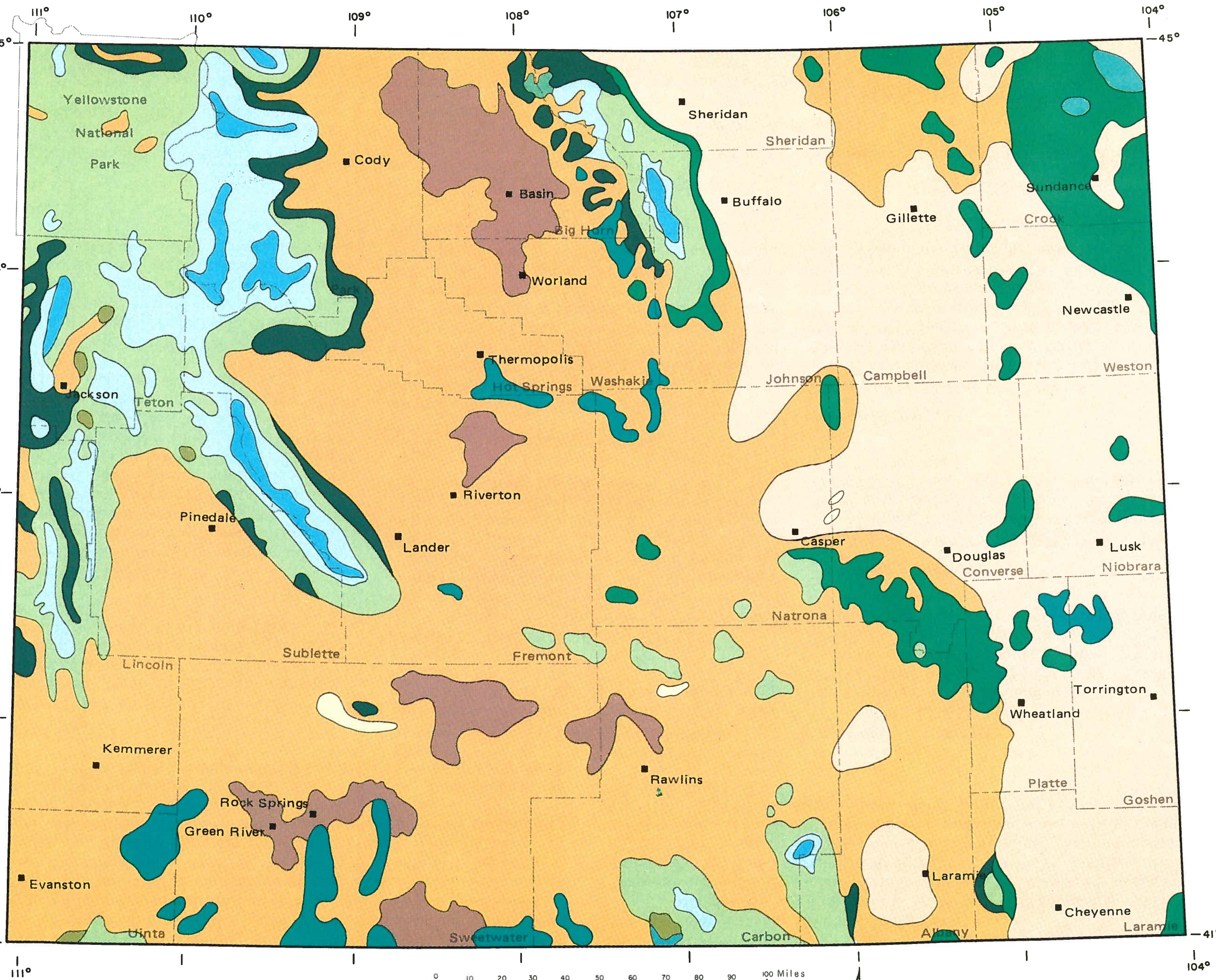
1. Dense forests to open woodlands dominated by Douglas fir, with an understory of grasses, herbs, and shrubs. Ponderosa pine, limber pine, and lodgepole pine also may be present.
2. Low elevations in the mountains, excluding the Black Hills and Bearlodge Mountains; often just above ponderosa pine. Often interspersed with foothill grasslands. Also common along the northern edge of Yellowstone National Park.

LODGEPOLE PINE FOREST

1. Dense to open forests dominated by lodgepole pine, with an understory (sometimes sparse) of grasses, herbs, and shrubs. Subalpine fir, Engelmann spruce, and aspen are common associates. Limber pine, whitebark pine, and Douglas fir may be present in some areas.
2. Very common at mid-elevations of all mountain ranges except the Black Hills and Bearlodge Mountains. Often interspersed with mountain meadows and aspen groves.

ASPEN FOREST

1. Broadleaf deciduous forests and woodlands dominated by aspen, usually with a dense understory of grasses, herbs, and shrubs. Common tree associates include Douglas fir, lodgepole pine, and subalpine fir.
2. Upper foothills and mid-elevations of all mountain ranges, usually in relatively moist habitats. Often occurs in small groves.



Map and explanation compiled by Dennis Knight, 1989.
(Modified from Choate, 1963; Kuchler, 1966; Garrison and others, 1977; Anderson and Inkley, 1983; Fallat and others, 1987; Despain, 1973; and Greater Yellowstone Coordinating Committee, 1987.)

Cartography by Phyllis A. Ranz

PLACES TO SEE GEOLOGIC DISPLAYS IN WYOMING
(with population data, major towns, and roads)

Where can you go in Wyoming to see exhibits of rocks, minerals, fossils, and other geologic material? This list of public museums and other places was compiled from my own travel notes, from responses to a questionnaire I mailed to many museums around the State, and from *Guide to museums in Wyoming* (Wyoming State Archives, Museums and Historical Department, 1982). Some of these exhibits are outstanding resources for the people of Wyoming and travelers to the State; we are indebted to the citizens and organizations or agencies who assembled and maintain them.

The list does not include the many rock, mineral, and fossil shops in the State, but these are highly recommended as sources of information and places to acquire your own samples. There are private collections available for study in some areas, but they are not described here.

The entries are as complete and up-to-date as I could make them, but there are undoubtedly some omissions or errors. The blank page at the end of this section is offered for additional notes and corrections. Admission to most of the exhibits was free at the time of this writing, but that may not always be true; some of the museums charge a small admission fee and many will cheerfully accept donations. Please check hours and admission fees when planning your visit.

ALBANY COUNTY

DINOSAUR BONE CABIN

Cabin built from Jurassic dinosaur bones. The famous dinosaur fossil site, Como Bluff, is nearby and a roadside marker briefly describes the area. Located southeast of Medicine Bow on U.S. Highway 30/287.

THE GEOLOGICAL MUSEUM

The best collection of dinosaur material in Wyoming; vertebrate and invertebrate fossils; rocks and minerals; related geologic displays. Exhibits are educational interpretive packages; occasional special exhibits. Guided tours available to groups with reservations. Located in the S.H. Knight Geology Building on the University of Wyoming Campus in Laramie. Open 8:00 a.m.-5:00 p.m., Monday-Friday (except major holidays); 10:00 a.m.-1:00 p.m. occasional weekends.

THE GEOLOGICAL SURVEY OF WYOMING

Rock and mineral displays including uncut Wyoming diamonds and diamond-bearing rocks; maps and books about all phases of Wyoming geology; geologic staff available to identify rock and mineral specimens and answer questions. Located in the Geological Survey Building on the University of Wyoming Campus in Laramie. Open 8:00 a.m.-5:00 p.m., Monday-Friday (except major holidays).

THE WYOMING CHILDREN'S MUSEUM

A hands-on museum. Exhibits change, some have geological themes (for example, rock and mineral identification and "gold" panning); workshops; guided tours for school groups and others by appointment. Located in rooms 253 and 254 in the Laramie Civic Center, 7th and Garfield, Laramie. Open Saturdays, 10:00 a.m.-4:00 p.m. and other hours by appointment.

BIG HORN COUNTY

BIGHORN CANYON RECREATION AREA VISITORS CENTER

Large geologic time display with examples of rocks from the local area, related to development of the canyon; books; geologic road guide for the area; guided natural history hikes include local geology. Located ¼ mile south of Lovell at the junction of U.S. Highway 310 and U.S. Alternate 14. Open 7 days/week, 8:00 a.m.-5:00 p.m., winters; 8:00 a.m.-6:00 p.m., summers.

GREYBULL MUSEUM

Rocks, minerals, more extensive fossil collection; display of local bentonite mining; earth-science slide programs; guided tours. Located at 325 Greybull Ave., Greybull. Open 10:00 a.m.-8:00 p.m., Monday-Saturday, June-August; reduced hours during other months (check with museum).

CAMPBELL COUNTY

CAMPBELL COUNTY ROCKPILE MUSEUM

Minerals, rocks, and a few fossils. Located at 1000 West 2nd (Highway 14/16 West), Gillette. Open 10:00 a.m.-8:00 p.m., Tuesday-Sunday, May 15-Ocotober 15.

CARBON COUNTY

GRAND ENCAMPMENT MUSEUM

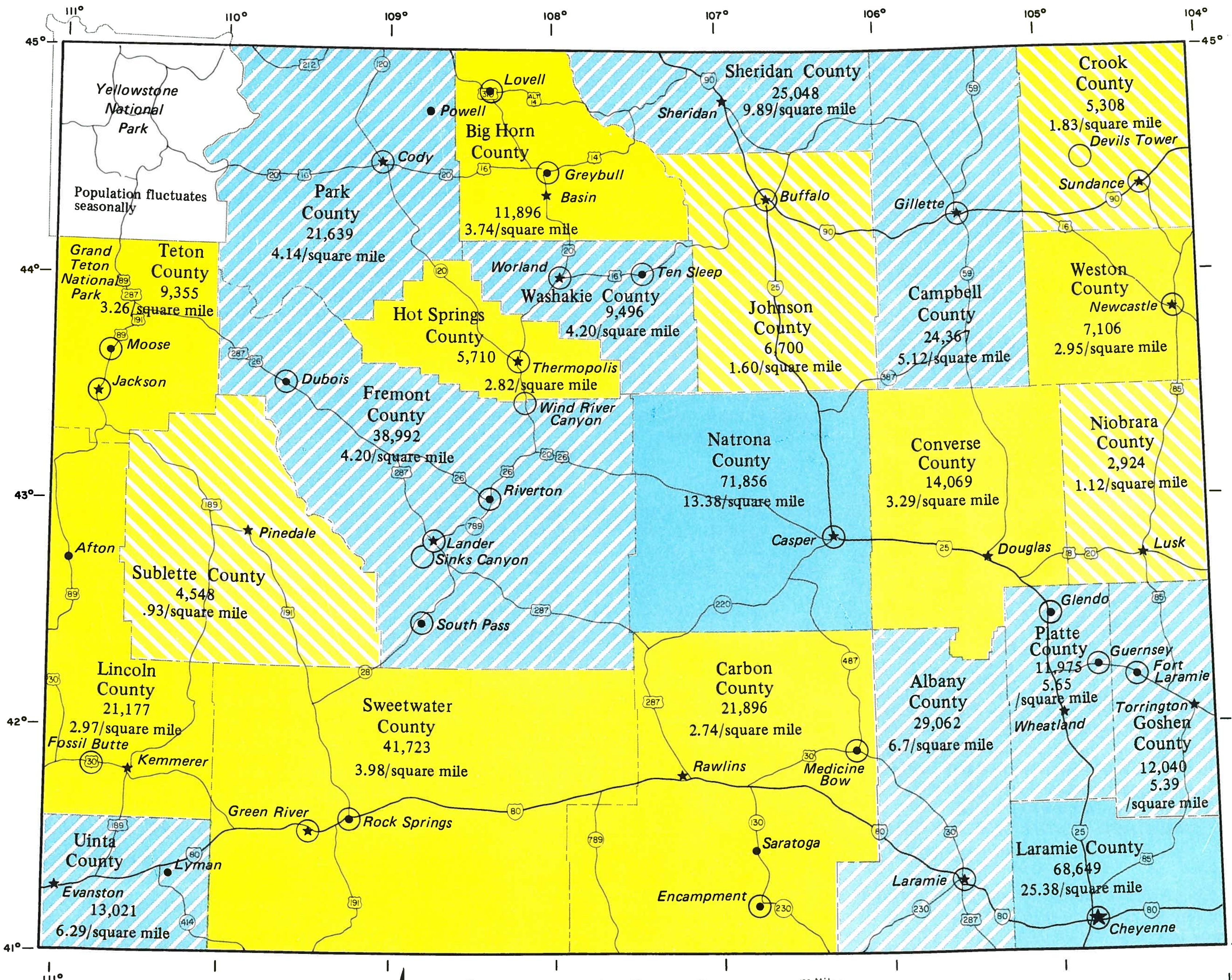
Rocks, minerals, fossils; exhibits of the Grand Encampment copper mining district at the turn of the century; books on local geology and mining history. Useful explanatory notes, guided tours. Located in Encampment. Open 1:00-5:00 p.m., 7 days/week, Memorial Day-Labor Day; Saturday and Sunday only, September and October.

MAP EXPLANATION

Teton County = County name
9,355 = Total county population
3.26/square mile = Population density in number of people per square mile
★ County seat
★ State capital
● Other important population center
○ Site of rock, mineral, or fossil display (see list).

Population density distribution (people per square mile)

- More than 10
- More than 4 and fewer than 10
- More than 2 and fewer than 4
- Fewer than 2



Population data from Wyoming Department of Administration and Fiscal Control (1987).

Cartography by Betty S. Wills and Phyllis A. Ranz

MEDICINE BOW MUSEUM

Local fossils, petrified wood. The University of Wyoming Geological Museum provides a summer exhibit of Como Bluff fossils and an excursion to the Como Bluff dinosaur sites. Located at 405 Lincoln Highway in Medicine Bow (old railroad depot). Open 10:00 a.m.-6:00 p.m., Wednesday-Monday, Memorial Day to Labor Day.

CROOK COUNTY

CROOK COUNTY MUSEUM AND ART GALLERY

Rocks, minerals, fossils. Located in Sundance. Open 9:00 a.m.-12:00 p.m. and 1:00-5:00 p.m., Monday-Friday.

DEVILS TOWER NATIONAL MONUMENT VISITORS CENTER

Geology display and the monument itself, an exhumed volcanic neck; video of Tower formation; books; self-guided trail includes geology of the area. Located west of Wyoming Highway 24 in northeastern Wyoming. Open 8:00 a.m.-7:45 p.m., 7 days/week, summers; reduced hours spring and fall; closed about November 1 to May 1 (plan to be open all year starting 1994).

FREMONT COUNTY

FREMONT COUNTY MUSEUMS, DUBOIS BRANCH

Minerals, rocks, fossils; Wind River Basin stratigraphic section; geology bookshelf. Guided tours. Located in Dubois. Open 10:00 a.m.-6:00 p.m., June-August.

FREMONT COUNTY PIONEER MUSEUM

Wyoming jade, a few fossils. Located at 630 Lincoln Street, Lander. Open afternoons Monday-Friday in winter; extended hours in summer (check with museum).

RIVERTON MUSEUM

Fossils, rocks, minerals; exhibits on local petroleum geology and uranium deposits. Located at 700 East Park in Riverton. Open 11:00 a.m.-6:00 p.m., June-September; 10:00 a.m.-4:00 p.m., October-May.

SINKS CANYON STATE PARK AND VISITOR CENTER

Rocks, minerals, fossils; displays of geologic time and the local stratigraphic column with appropriate rocks and fossils, how the Sinks works, types of fossilization; natural history videos; nature walk. Located in Sinks Canyon State Park, 7.5 miles southwest of Lander. Open 7 days/week Memorial Day through Labor Day.

SOUTH PASS CITY STATE HISTORIC SITE

Historic gold mining town. Rock and mineral display, slide show, guided tours. Located in South Pass City on State route 62 south of State Highway 28. Open 9:00 a.m.-6:00 p.m., May 15-October 15.

GOSHEN COUNTY

FORT LARAMIE NATIONAL HISTORIC SITE VISITORS CENTER

A few rocks and fossils from the local area, raised-relief map, books. Located at the historic site, southeast of Guernsey. Open sunrise to sunset, summers, shorter hours in winter.

HOT SPRINGS COUNTY

HOT SPRINGS COUNTY MUSEUM AND CULTURAL CENTER

Rocks, minerals, fossils; displays of geologic time and fluorescent minerals. Located at 700 Broadway, Thermopolis. Open 8:00 a.m.-5:00 p.m., Monday-Saturday; 1:00-4:00 p.m., Sunday (except major holidays).

WIND RIVER CANYON

The drive on U.S. Highway 20/Wyoming Highway 789 through the canyon north of Boysen Reservoir, while not exactly a museum, is a wonderful, annotated display of Wyoming geology. As the road cuts through the rocks, more than 2.5 billion years of geologic history is exposed. Road signs placed alongside the rocks record the formation name and age so that travelers can appreciate the tour through geologic time.

JOHNSON COUNTY

JOHNSON COUNTY JIM GATCHELL MEMORIAL MUSEUM

Rocks, minerals, fossils. Located at 10 Fort Street, Buffalo. Open 9:00 a.m.-8:00 p.m., Memorial Day to Labor Day (dates may be extended).

LARAMIE COUNTY

WYOMING STATE MUSEUM

Triceratops skull cast; rock and mineral samples and books in the Gift Shop. Located in the Barrett Building, Cheyenne. Open 8:00 a.m.-5:00 p.m., Monday-Friday; 1:00-5:00 p.m. Saturday and Sunday (summers).

WYOMING STATE CAPITOL

Small display of Wyoming rocks and minerals on the second floor of the Capitol Building. Open 8:00 a.m.-5:00 p.m., weekdays except holidays.

LINCOLN COUNTY

FOSSIL BUTTE NATIONAL MONUMENT

Green River Formation fossil fish, plants, etc. display; self-guided and naturalist-guided hikes on Fossil Butte; campfire programs. Located 10 miles west of Kemmerer on U.S. Highway 30. Open 8:30 a.m.-5:30 p.m., 7 days/week, summers (about May 20-September 10). (New facility is scheduled to be open all year starting in 1990.)

NATRONA COUNTY

TATE MINERALOGICAL MUSEUM

Features geologic history of the area, local fossils and minerals, extensive jade collection; guided tours for school groups and others by appointment. Located in the Tate Building on Casper Mountain Road in Casper. Irregular hours, call (307) 268-2514 or Casper College.

PARK COUNTY

CODY FIFTY-NINERS ROCK CLUB EXHIBIT

The club maintains a display of local rocks, gems and fossils at the Bureau of Land Management Office in Cody. The display is changed annually, about May 1. Located at 1714 Stampede Avenue.

PLATTE COUNTY

FREDERICK MUSEUM

Large unclassified collection of rocks and minerals. Located 2 miles west of Guernsey on U.S. Highway 26. Open 10:00 a.m.-4:00 p.m., weekdays.

GLENDO HISTORICAL MUSEUM

A few rock and mineral specimens; more extensive fossil display correlated with geologic time; guided tours. Some fossil material available for study that is not displayed. Located at the Town Hall, Glendo. Open 8:00 a.m.-12:00 p.m., Monday-Friday and 1:00-4:00 p.m. on request.

GUERNSEY MUSEUM

Some local rocks and minerals. Located at the southwest corner of City Park. Open 8:00 a.m.-8:00 p.m., mid May-end of September.

GUERNSEY STATE PARK MUSEUM

Rocks, minerals; displays of agate, iron, and onyx mined locally, prehistoric rock quarry, creation of Guernsey Canyon; some geology books. Located near Guernsey. Open May 15-September 10.

SWEETWATER COUNTY

GREEN RIVER CHAMBER OF COMMERCE/U.S. FOREST SERVICE INFORMATION CENTER

Large raised-relief map of the Flaming Gorge area; trona display (samples, mining, processing, products); geological maps and area information. Located at 1450 Uinta, Green River. Hours 9:00 a.m.-12:00 p.m. and 1:00-4:30 p.m., Monday-Friday.

SWEETWATER COUNTY HISTORICAL MUSEUM

Fossils, minerals, rocks; mining history (coal, trona, and oil shale); guided tours. Located in the courthouse at Green River (80 West Flaming Gorge Way). Open 10:00 a.m.-4:30 p.m., Monday-Friday except holidays.

WESTERN WYOMING COLLEGE MUSEUM

Fossil fish, mammals, growing collection of dinosaurs; tours by arrangement. Located on the Western Wyoming College Campus in Rock Springs. Open 7:00 a.m.-10:00 p.m., Monday-Friday.

TETON COUNTY

GRAND TETON NATIONAL PARK VISITORS CENTER

Interpretive center with information and displays on the geology of the park; maps; books. Guided tours, talks, and slide shows during summer months. Located at Moose. Open 8:00 a.m.-4:30 p.m. (reduced winter hours).

JACKSON HOLE MUSEUM

Displays of mining history in Jackson Hole; minerals and rocks used in Indian arrowheads. Located at 105 North Glenwood, Jackson. Open 9:00 a.m.-9:00 p.m.

WASHAKIE COUNTY

TEN SLEEP MUSEUM

A few rock, mineral, and fossil specimens. Located in Ten Sleep. Open 1:00-4:00 p.m., Memorial Day to Labor Day.

WASHAKIE COUNTY MUSEUM AND CULTURAL CENTER

Rocks, minerals, fossils. Some exhibits change every two months, may include other geology displays. Located at 1115 Obie Sue Avenue, Worland. Open 10:00 a.m.-5:00 p.m., Monday-Friday, all year; 2:00-5:00 p.m., Saturday and Sunday, summers.

WESTON COUNTY

ANNA MILLER MUSEUM

Extensive collection of fossils, rocks, minerals; displays of Black Hills uplift, geologic formations; geology books; guided tours. Will take museum exhibits to schools. Located on Delaware Street, Newcastle. Open 9:00 a.m.-5:00 p.m., Monday-Friday, after hours by appointment.

YELLOWSTONE NATIONAL PARK

Of course, the whole park is a fantastic geology exhibit. Several of the visitors centers have good displays and other explanatory material (specialties in parentheses): *Canyon Visitor Center* (geology and other natural history) *Fishing Bridge Museum* (Yellowstone Lake geology), *Norris Museum* (geothermal phenomena), *Old Faithful* (geyser activity). Ranger talks, guided tours, and slide shows sometimes feature geological subjects. (Check for hours).

POPULATION MAP

A population map is included in this compilation because geology affects population by influencing the type and amount of economic development that can occur and because people always make an impact on the land. The information on the map is from the last official census, taken in 1980. At that time, the total population in Wyoming was 469,557, ranking Wyoming 49th in the United States. A 1985 estimate placed Wyoming as the least populated state, with 509,000 people (information from the U.S. Bureau of Census, compiled by the Wyoming Economic Development and Stabilization Board).

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MORE PUBLICATIONS FROM THE GEOLOGICAL SURVEY OF WYOMING

MAPS

GEOLOGIC MAP OF WYOMING (Scale 1:500,000)

WYOMING GEOLOGIC HIGHWAY MAP (Scale 1:1,000,000)

WYOMING MINES AND MINERALS MAP (Scale 1:500,000) [MS-5]

LANDSAT IMAGE MOSAIC OF WYOMING (Scale 1:500,000) [MS-11]

OIL AND GAS MAP OF WYOMING (Scale 1:500,000) [MS-12]

METALLIC AND INDUSTRIAL MINERALS MAP OF WYOMING (Scale 1:500,000) [MS-14]

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BOOKS

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WYOMING'S MINERAL AND ENERGY RESOURCES IN GEOLOGIC TIME

TIME[1]	ERA	PERIOD	EPOCH	SOME GEOLOGIC RESOURCES IN WYOMING[2]
0	CENOZOIC	Quaternary	Holocene	Sand and gravel, placer gold, travertine, sulfur, diatomite, clinker, sodium sulfate, epsomite.
1.6			Pleistocene	
5.3		Tertiary	Pliocene	Diatomite, pumicite, agate.
23.7			Miocene	Agate.
36.6			Oligocene	Copper-molybdenum porphyries, paleoplacer gold.
57.8			Eocene	Uranium, coal, trona, oil shale, zeolites, gold paleoplacers, rare earths, fluorite, thorium, copper-molybdenum porphyries.
			Paleocene	Uranium, coal, natural gas.
66.4	MESOZOIC	Cretaceous		Oil and gas, coal, bentonite, silica sand, titaniferous black sandstone paleoplacers, uranium.
144		Jurassic		Gypsum, oil and gas, silica sand, copper-silver-zinc.
208		Triassic		Gypsum, oil and gas.
245	PALEOZOIC	Permian		Phosphate rock and associated vanadium, oil and gas, gypsum.
286		Pennsylvanian		Limestone, oil and gas, silica sand, copper.
320		Mississippian		Limestone, oil and gas, hematitic quartzites ("Rawlins red").
360		Devonian		Limestone, oil and gas, diamond-bearing kimberlites.
408		Silurian		
438		Ordovician		Oil and natural gas (including helium and carbon dioxide), dolomite and limestone.
505		Cambrian		Silica sand; paleoplacer gold, thorium, and rare earths; oil reservoir rocks.
570				Major unconformity
1,400	PRECAMBRIAN	PROTEROZOIC[3]		Anorthosite. Gold, copper, platinum. Copper and gold. Volcanogenic copper-silver-zinc. Tantulum- and niobium-bearing mafic dikes. Gold-bearing quartz veins. Copper-bearing quartzite. Uranium paleoplacers. Railroad ballast from quartzofeldspathic rocks and metadolomites. Hematite iron ore (probable Proterozoic age, may be partly Archean).
2,500		ARCHEAN[3]		Pegmatites containing beryl, lepidolite, feldspar, and copper sulfides. Jade, sapphires, rubies. Banded magnetite iron formation. Uranium paleoplacers. Gold-bearing veins and shears. Talc and asbestos.
4,600				

[1] In millions of years before present (from Geological Society of America 1983 Geologic time scale).
[2] In different areas of Wyoming, rocks of nearly all ages act as aquifers for ground water.
[3] Resources not necessarily in chronological order.

STATE OF WYOMING
1933
GEOLOGICAL SURVEY

Geology--Interpreting the past to provide for the future