Oklahoma Geological Survey

OKLAHOMA GEOLOGY notes

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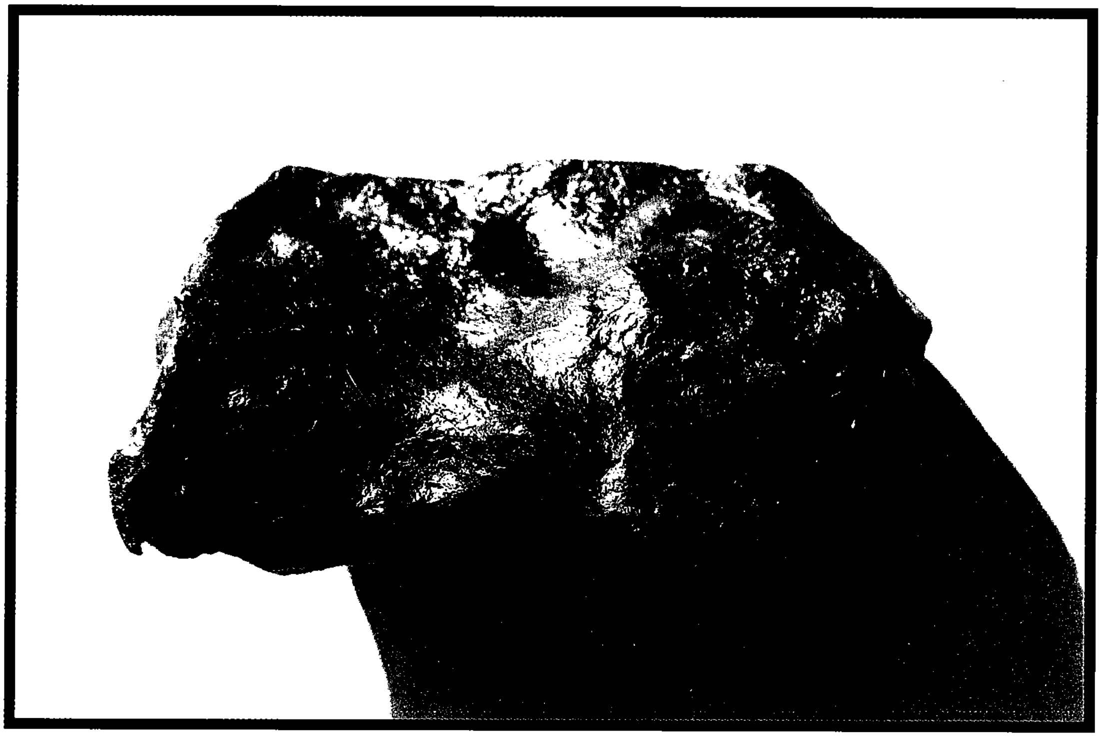

Featuring:
- *Identification and understanding of minerals*
- *Earth-science and rockhound programs*
- *Fossil collecting and cleaning*
- *Meteorites*

on the cover

The Yukon meteorite

In 1975, a young couple found a strange, heavy, dark brown rock (see the photograph on the cover) ~7 mi north of Yukon, Oklahoma, near the intersection of Highways 3 and 4, in Canadian County. Curious about what it was, they took it home for further study. Still undecided about it, they brought it to me at the University of Oklahoma to see if I could provide any information. To me, the rock looked like a piece of iron that might be an iron meteorite. I suggested that they leave the specimen with me to see if a microscopic thin section prepared from it would allow a positive identification. The preparation did, indeed, allow identification of the specimen as an iron meteorite in the octahedrite class.

According to precedent, a meteorite is named after a geographic location near the place where it was found. Thus, this new Oklahoma meteorite is named "the Yukon meteorite." The new specimen, which is now awaiting formal recognition and name designation, is dusky yellowish brown (10YR2/2) and moderate brown (5YR3/4) in color and measures 7 × 5 × 2.5 cm. Intact, it weighed 915 g, but it has been cut into three pieces for further study. The meteorite is composed essentially of kamacite and taenite (nickel and iron minerals), with very minor amounts of schreibersite and possibly troilite. The surface of the specimen is marked by regmaglypts, the typical thumbprint-like depressions caused by gas erosion of surface material as a meteorite passes through the Earth's atmosphere.

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Preface to the articles in this issue

Much of Oklahoma's wealth—past and present—is due to its unique geology. And much of its future well-being depends on Oklahomans understanding, appreciating, and using wisely the State's natural resources. A key to understanding our natural resources is earth-science education, starting in elementary school (or before) and continuing through college (and beyond). The Oklahoma Geological Survey (OGS)—along with professional geologists and gem, mineral, and fossil collectors ("rockhounds")—assists earth-science educators throughout the State in a variety of ways, including classroom demonstrations, field-trip leadership, and curriculum development. This issue of *Oklahoma Geology Notes* continues that effort.

On October 16–17, 1997, the OGS, in cooperation with the Oklahoma Science Teachers Association (OSTA), the Gem and Mineral Clubs of Oklahoma, and a group of earth-science teachers and professional geologists, presented an earth-science workshop and field trip at the fall meeting of the OSTA. The workshop was held at the Allan Chapman Activity Center, University of Tulsa, on the first day and featured nine presentations of interest to teachers and students. Subjects ranged from minerals and fossils to meteorites to using the Internet. On the second day, many teachers attended a field trip in the Tulsa area.

After the workshop, five of the speakers volunteered to submit their presentations to the OGS for publication. These authors represent the range of geological expertise in Oklahoma that is available to earth-science educators. Two articles (DuBois; London and Soreghan) are contributed by members of a university faculty; two (Charbonneau; Osborne) are from members of gem and mineral clubs; one (Stitt) comes from a State agency employee. Other presenters at the workshop and on the field trip were from State and Federal agencies, a petroleum company, universities, and a high school; one was a petroleum consultant.

This issue of *Oklahoma Geology Notes* contains five of the presentations made at the 1997 OSTA Earth-Science Workshop. Each article should be useful not only to earth-science educators but to anyone interested in Oklahoma's geology. Furthermore, the articles provide a permanent record of the willingness—indeed, eagerness—of the professional and amateur geological community to assist in the education of Oklahoma's young people.

Sincere thanks are expressed to all workshop and field-trip speakers and especially to those who contributed to this issue of the *Notes*.

KENNETH S. JOHNSON AND
NEIL H. SUNESON
Chairs, 1997 OSTA Earth-Science Workshop Organizing Committee

Members of the 1997 OSTA Earth-Science Workshop Organizing Committee and their affiliations at that time:

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John Charbonneau, *Stillwater Mineral and Gem Society*
Dwight Davidson, *Kellyville Public Schools*
Richard Dodrill, *Tulsa Rock and Mineral Society*
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EDITORIAL MATTER: Short articles on aspects of Oklahoma geology are welcome from contributors; please direct questions or requests for general guidelines to the *NOTES* editor at the address above.

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OKLAHOMA GEOLOGY notes

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Identification and Understanding of Minerals

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INTRODUCTION

The bulk of Earth and the other planets (so far as we know) belongs in the mineral kingdom. This predominance alone of mineral material in our planetary system is a compelling reason for educating the public about minerals. Minerals are also the principal source of metals (everything we use that is composed of metallic components!), many building materials, gemstones, and fuels for nuclear energy. This practical aspect of mineralogy should be a matter of common public awareness, though of course it is not. Much of history, from ancient global conquests to current political alignments, was dictated by the need for and the sharing of mineral wealth among haves and have-nots.

DEFINITION

The definition of a mineral should be simple, but in fact exceptions and unusual circumstances cloud the issue. The simplest definition might include these attributes: (1) natural occurrence, (2) crystalline structure, and (3) composition—element vs. compound.

Natural occurrence means formation by natural forces without human intervention (as opposed to anthropogenic or synthetic substances). One definition still being debated (Nickel, 1995) holds that biologically produced materials with the attributes of minerals shall not be considered minerals unless acted upon by geologic processes. However, much disagreement exists about this point, as many mineralogists feel that biogenic crystalline compounds such as bone, shell, and bacterially mitigated sulfides are minerals as formed.

Crystallinity refers to an orderly arrangement and periodic repetition of atoms through a substance. Only solids can be crystalline; hence the mere definition of crystallinity implies that liquids and gases are excluded from the mineral kingdom. True to this definition, water is not a mineral, but ice—crystalline H_2O—is a mineral. Elements and compounds comprise all possible arrangements of the chemical elements—as pure substances and as mixtures. Though most textbooks state that a mineral must be inorganic in origin, several dozen accepted minerals are actually organic. Many texts add to their definition of a mineral a statement that defines or sharply restricts the composition; however, most minerals are solid solutions, and many exhibit variations in composition within a single crystal, and hence lack the uniformity and rigidly defined composition generally implied. A mineral species does indeed have a specific, fixed composition that can be uniquely expressed through a chemical formula. For example, the species albite is represented by the precise formula $NaAlSi_3O_8$. It is not necessary that pure $NaAlSi_3O_8$ exist—only that a mineral with >50% $NaAlSi_3O_8$ exist! Plagioclase represents a mineral series whose composition can vary continuously between $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$, even within a single crystal. Add $KAlSi_3O_8$ and we derive an important mineral group—the feldspars, which are the most abundant minerals in the Earth's crust—whose composition varies mostly within the range of $KAlSi_3O_8$—$NaAlSi_3O_8$—$CaAl_2Si_2O_8$ (but other components are required to fully define the feldspar group). Thus any mineralogist would agree that feldspar is a mineral, though the composition of feldspar may vary widely between the possible end-member components. A recent mineralogical report (Leake and others, 1997) defines the common mineral group known as the amphiboles in terms of 18 known mineral species!

MINERAL IDENTIFICATION

Minerals are found most commonly as grains of solid rock or of unconsolidated materials such as sand or soil. Hence, mineral identification in a hand specimen (with or without the aid of magnification) should focus on the attributes of minerals that are most readily visible. These are color, luster, cleavage, and habit.

Although color is not diagnostic of most minerals, the human eye usually (not always) can distinguish hue and intensity (also called saturation) with amazing subtlety. Thus we tend to rely on what we discern most clearly.

Luster pertains to the way light is reflected from mineral surfaces. Some differences of luster are sharply evident to the eye, e.g., metallic (shiny like metal) versus vitreous (glassy). Other terms for luster are more subtle (silky, greasy, etc.). Luster is described only in the general, non-quantitative terms that are implied by the everyday meaning of the words (e.g., silky, greasy). However, reflectivity can be a quantitative measure of the amount of light that is reflected from a surface and hence can be used to precisely identify a mineral.

As most minerals are observed in rocks and as loose grains, they present broken surfaces—fragments broken from the solid Earth. How a mineral breaks is mostly a function of its composition and internal crystalline order. If there is no preferred direction in which a mineral breaks, its surfaces will appear irregular and rough, without flat or planar elements. This is fracture, which ranges from hackly (rough) to conchoidal (curved, like the surface of a sea shell). Most minerals have certain planes or directions in which the bonds holding the mineral together are weaker than in other directions: a mineral breaks along planes where the bonds are weakest; that imparts cleavage. Cleavage has quality (fair, good, excellent, perfect) and direction (one direction, two directions at some angle to one another, and even three directions (as in common table salt).

Like luster, habit is used to describe the general shape of a mineral grain. Consequently, we use general terms for habit (e.g., blocky, tabular, bladed, radial) and others that are amazingly specific yet descriptive, e.g., reniform, which means shaped like a kidney, and botryoidal, shaped like a bunch of grapes. View any of those shapes in your mind's eye and you'll understand why habit can be a very effective means of discerning and expressing the appearance of a mineral. Habit shouldn't be confused with form, which in mineralogy refers specifically to the geometric pattern of atomic structure within a mineral; a pattern may or may not have outward expression as crystal faces or cleavage.

Among the physical tests (as opposed to visual), hardness is probably used most often. The hardness of a mineral reflects the nature and strength of the chemical bonds holding the mineral's atomic constituents together—the more strongly bonded the atoms, the harder the mineral. Mineralogists use a scale of relative hardness from 1 to 10; it is known as the Mohs scale, and is calibrated with respect to certain fresh minerals that exist as nearly pure end-member species. "Fresh" is emphasized because many minerals contain inclusions or are altered on a fine microscopic scale—circumstances that may change the apparent hardness. Also, the Mohs scale is not absolute, as is the Vickers or indentation hardness tests. In contrast to absolute hardness, the Mohs scale is not linear; the difference in hardness between Mohs 9 and 10 is much greater than between Mohs 1 and 2.

Numerous other physical tests (as opposed to the visual) are specific to one mineral or to a small group of minerals. For example, natural magnetism is a property of an iron-rich mineral called magnetite. Also, calcite is a common mineral (it makes up limestone and marble) and reacts with acids such as hydrochloric acid (HCl) or even vinegar. Many of these special properties of minerals are described in any good field guide from your library or bookstore.

Because the physical properties of a mineral reflect its chemical composition and atomic structure, reliable identification of many minerals can be made using physical properties alone. However, because of solid solution in minerals, most identification schemes based on physical properties are calibrated for specific end members, and physical properties might vary significantly if the mineral tested is not an end-member species. Most identification schemes based on physical properties use a hierarchical approach (Fig. 1) where students answer a question about a physical property of an unknown mineral, and, depending on the result, are guided along a branch to another question in which members of a smaller subset share the previous physical property. For example, if a mineral is determined to have a metallic luster, then the classification scheme will branch, so that only those minerals with metallic luster ultimately fall along that branch. In this way the potential group of minerals shrinks as more physical properties are tested.

In theory, if all the physical properties for an unknown mineral are identified correctly, the classification scheme leaves only one possible choice for the mineral. Most determinative tables of mineralogy rank color or luster at the first level of identification. The only shortcoming of these hierarchical classification schemes is that if a student misidentifies any one physical property of a mineral, the student will be led down the wrong path with no chance of identifying the mineral correctly.

Another means of classifying minerals is a matrix (Fig. 2): mineral names are listed in the rows of a table and physical properties in the columns. If a mineral has the specific property identified by the column then the cell of the matrix is filled in. To use the table, then, a student identifies the properties of the mineral and compares the answer with the mineral names in the matrix. The mineral name in the matrix most closely matching the physical properties observed will presumably be the correct identity.

In order to acclimate students to hierarchical classification schemes it is sometimes useful to ask them to develop their own schemes using common objects—paper clip, safety pin, pencil, pen, marble, rubber ball, penny, etc. For younger students candies can be used, such as chocolate kisses, gummy bears, jawbreakers, and M&Ms. The students can define properties by declaring "all these are metallic," or "all are round." They can then compare their classification schemes with those used for minerals.

LABORATORY EXERCISES IN MINERALOGY

Laboratory exercises in solid earth science (geology and geophysics) should serve as preparation for actual field studies or as analogies to processes that cannot be readily or easily observed in the field. Manuals of laboratory exercises abound for college-level courses. The exercises focus mostly on teaching standard methods (reading geologic maps, learning minerals and rocks, etc.) that a practicing geologist or geophysicist must know; they tend to be full of exercises that are necessary but may be dull. Most K–12 teachers need only a few laboratory exercises if they are easy to prepare and execute by individuals or small groups, and are also inexpensive, quick to execute with predictable results, safe, and (perhaps most important) engaging and fun for the students. For older students (high school and college) novel experiments can infuse a course with more interest than conventional exercises.

The following two sections describe the complex process of mineral growth. Where appropriate, we refer to experiments (described in the Appendix) that are intended to simulate or verify the points being made in the text. The exercises are short, easy, inexpensive (relatively but variably), safe with normal precautions, and fun (as evidenced by student response). The exercises stem mostly from our own expertise and experience. Each exercise lists the materials required, describes the procedure, and proposes questions for discussion.

How Do Crystals Grow?

Nothing is more fundamental to solid earth science than understanding how crystals grow. In general, people are surprised to learn that minerals go through cycles or periods of growth and disappearance. This is not news to mineralogists and crystal engineers, who utilize terms for crystal growth that are very similar to those of biological systems. The terms "nutrients," "unit cell," "nucleus," "embryo," "seed," and so forth are commonly employed in the science of crystal growth.

In common rocks, minerals precipitate from fluids (liquids, gases, solutions, etc.) usually by one of three means: cooling,

Mineral Identification Flow Chart

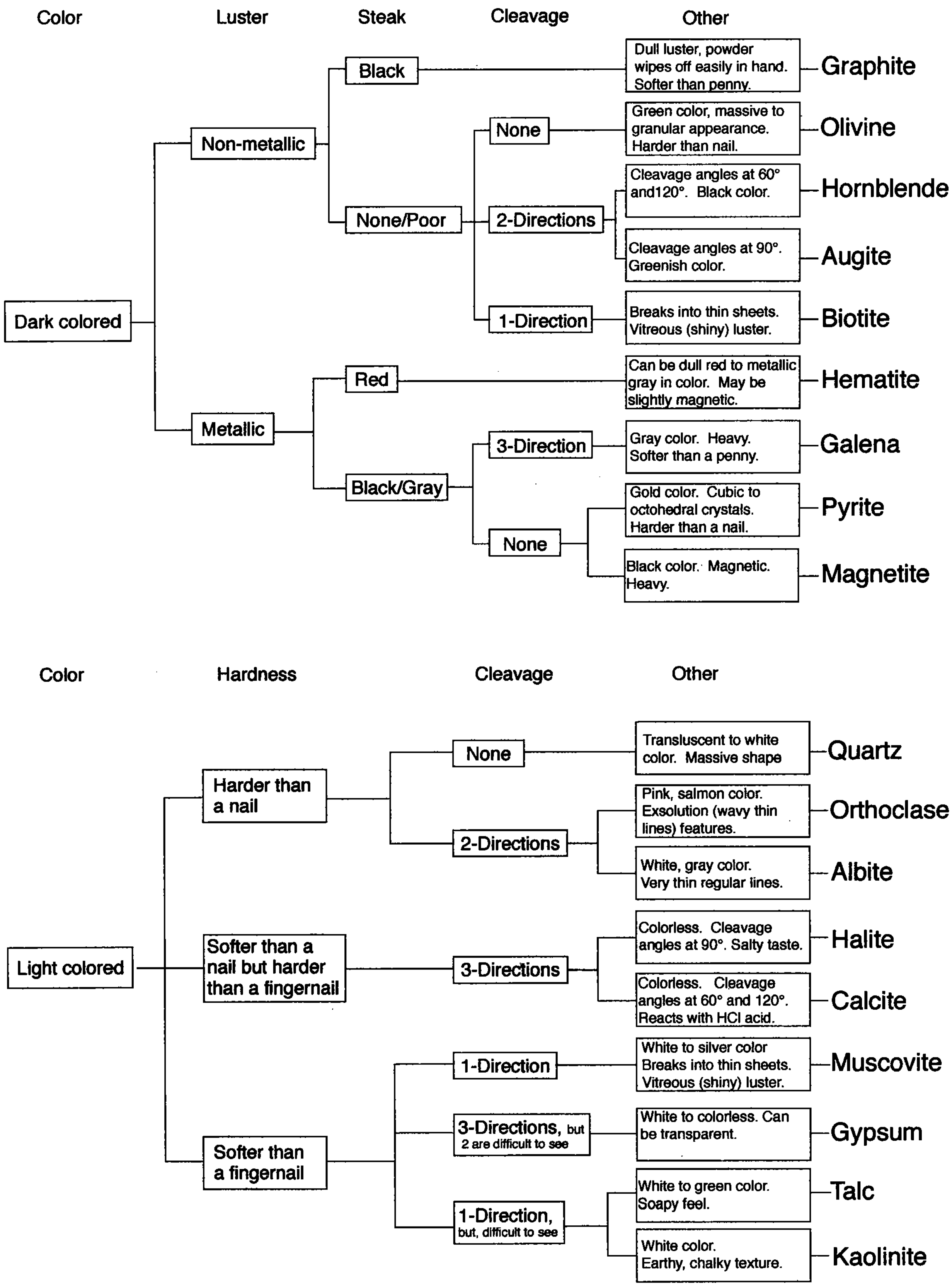

Figure 1. A hierarchical mineral identification chart. This chart is organized with color as the first discriminator.

property / Mineral	color			luster						streak			cleavage						hardness			reation to acid	magnetism
	black/gray	red/brown/gold	white/colorless	metallic	vitreous	pearly	silky	earten	greasy	resinous	black/gray	red/brown	white/colorless	fracture	1-direction	2-direction @90°	2-direction @60-120°	3-direction @90°	3-direction @60-120°	> steel nail	< steel nail, but > a fingernail	< a fingernail		
Albite			●		●								●			●				●				
Amphibole	●				●						●						●				●			
Biotite	●				●						●				●						●			
Calcite			●		●								●						●		●		●	
Galena	●			●							●							●			●			
Gypsum			●		●								●					●				●		
Kaolinite			●					●					●	●								●		
Magnetite	●			●							●			●						●				●
Muscovite			●		●								●		●						●	●		
Pyrite		●		●							●			●						●				
Quartz			●		●								●	●						●				
⋮																								

Figure 2. This is a mineral identification matrix. Students can measure the physical properties of an unknown mineral and then compare results with the matrix. The mineral with the most matches is the likely identity of the mineral. A shortcoming of the method is that mineral properties do vary somewhat, so the matrix should include ranges (e.g., see the hardness of muscovite).

evaporation, or chemical reaction. Each process can be demonstrated in a lab (Appendix, experiments 1–4) with reference to natural examples (either as hand specimens or in the field).

Experiment 1 simulates the process by which magmas, which are comprised mostly of molten rock material, solidify by crystallization upon cooling. In nature, the resultant rock would be igneous in origin, including volcanic rocks and their intrusive (subterranean) counterparts.

Experiment 2 replicates the process of crystallization by cooling from the other important natural fluid—water. We most clearly see this process manifested as veins of minerals that precipitate on the walls of fissures in rock. However, the process also serves to bind or cement grains by the movement of ground water through sediments. We note that among the experiments listed in the Appendix, experiment 2 is somewhat unreliable for the reason that most commercial salt products contain agents that prevent crystals from nucleating; hence for best results, we recommend rock or livestock salt that has not been treated.

Experiment 3 reliably depicts the growth of crystals by the evaporation of water. Most salts, including common table salt and the gypsum crystals in the Salt Plains Wildlife Refuge of northern Oklahoma, form in this fashion.

Experiment 4 not only is reliable but quick to set up and easy to perform, and it is but one way to demonstrate that minerals may precipitate by chemical reactions that take place in fluids. Experiment 4 is not suitable for students to perform, but it may be conducted safely by an instructor. At issue is the use of barium chloride solution, whose toxicity is not well known but is presumed harmful if ingested. However, the experiment can be linked directly to the formation of Oklahoma's state rock, the barite rose.

Experiment 5 can be connected to the process of crystal growth. It can be performed only when seasonal conditions favor the build-up of static charge on suitable materials. Moreover, finely milled mica is rather difficult to locate. However, for advanced students who seek proof that the surfaces of minerals are charged, it provides a compelling demonstration.

Experiment 6, as noted below, pertains to the dissolution of minerals rather than their growth.

Why Do Crystals Grow?

To explain why crystals grow, one needs to start with the very basic concept of chemistry: the nature of the chemical bond. When atoms combine to make either elements or compounds, they do so because the association of atoms is more stable than the isolated existence of the atoms. The way in which atoms bind to become more stable entails the sharing (or movement) of electrons between the atoms. With the displacement of electrons between atoms, the atoms themselves can acquire an electrical charge—negative when an atom gains electrons, positive when electrons are lost. The charged atoms are ions and for the purposes of electrical balance are assigned formal charges such as 4+ and 2–. As can be demonstrated with permanent magnets, opposite charges (like opposite magnetic poles) attract, and like charges (magnetic poles) repel one another. In this ionic model for minerals, which is one of a set of rules of order for minerals that were expounded by Linus Pauling (1960), the charge of any given atom is balanced by equal charge of opposite sign coming from surrounding atoms, and hence an atom that lies entirely within the crystal structure has a fully satisfied charge balance. However, suppose an atom lies on a surface, edge, or corner of a real crystal: the charge of the ions must not be fully balanced; they are not completely surrounded or enclosed in the mineral. The electrical charge of ions at the surface, edges, and corners of a crystal attracts new ions to that crystal. The more exposed the ion and the higher its charge, the more strongly it attracts material with the opposite electrical sign. In general, ions are more satisfied along planar surfaces, less so along edges, and least so at corners. Hence, corners are the regions of highest electrical energy on a crystal, and those most likely to grow or dissolve. In Experiment 1, the crystals that grow from molten moth crystals (or other liquid) grow as thin needle-like crystals in a radial spray. The needles are actually corners of a crystal structure that grow out as lines, leaving the edges and (especially) the faces behind. To demonstrate that corners and edges are the places where crystal growing energy is concentrated, consider the effect of dissolving a fragment of halite in experiment 6 (Appendix). When sharply bounded crystals or cleavage fragments of halite or other salts are made to dissolve quickly, the most rapid dissolution takes place at the corners and is manifested by pronounced rounding of the corners and edges.

MINERALS VIA THE INTERNET

The Internet—notably its World Wide Web—is an exploding technology and a vast array of information sources. However, Web sites may disappear or change addresses; owners do not always keep their sites up to date; their information may not be reliable. Nevertheless, using the Internet in the classroom can provide a wealth of information about properties, use, and occurrence of minerals. Some popular Web sites are:

Smithsonian Institution:
http://www.si.edu/resource/faq/nmnh/mineralsciences/htm

Mineral Gallery (a commercial site, with many good images):
http://www.galleries.com/

Mineralogical Society of America:
http://www.minsocam.org/

Because Web sites may be ephemeral, it is best to use a good search engine to seek out many more sites dealing with mineral collecting, precious metals, crystals, and similar topics. One simple method to get students to use information about minerals on the Web is to provide a worksheet and a list of Web sites they must visit to answer the questions.

Alternatively, assign topics for research on the Web, such as (1) What is the most economically important mineral for a certain country?; (2) What is the real health hazard from "asbestos"?; (3) Where do most diamonds come from? These topics are easily researched on the Web and can lead to group discussions, poster projects, and written reports.

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EXPERIMENT 1

Crystal Growth by Cooling from Melt

(simulates formation of igneous rocks)

Needed:

- Two glass plates or microscope slides (or microscope slide and cover slip)
- Moth crystals (from a drugstore) or melting-point standards (from a scientific supply house)
- Electric hotplate
- Overhead projector or microscope

Procedure:

Place a small quantity of moth crystals or melting-point standard between glass plates or slides. Place the sandwich on the hotplate until the crystals melt; the melt should flow out to the edges of the covered slides. Transfer the glass sandwich to the overhead projector or microscope. As the melt cools, crystals form radial clusters that grow toward the center of the slide or plate, or wherever cooling proceeds more slowly.

> *CAUTION:* Fumes from moth crystals (thymol) and melting point substances can irritate the eyes. Avoid heating the samples to the point of fuming, and handle the hot slides with tongs or suitable gloves.

Representation:

The material, once melted, represents a magma. As a magma cools, energy is released as heat escapes. As heat escapes from the liquid, the atoms move close to each other and begin to bond. As cooling progresses, more and more atoms bind together and form a solid. Fast cooling promotes rapid growth of crystals from magma; in obsidian they appear as spherulites. Upon slower cooling, the crystals adopt more regular shapes and grow randomly through the melt.

Natural Examples:

Igneous rocks can be found in the Wichita igneous province of southwestern Oklahoma, where some in fact have textures similar to those grown in this exercise. Other exposures of igneous rocks occur in the Arbuckle Mountains (the Colbert Rhyolite) and in the vicinity of Mill Creek and Tishomingo.

Pyrite "dollars" are representative of rapid 2-D growth as seen in this experiment; "snowflake" obsidian contains spherical 3-D radial aggregates of cristobalite and feldspars.

*Questions for discussion:**

Q: Where do crystals first begin to form? Where do the last crystals form? Why is this so?

A: *The first crystals begin to form around the edges of the glass slide. Crystallization then proceeds from the edges inward, so that the last crystals to form are toward the middle of the slide. This is because the edges of the slide cool most rapidly, and therefore the melt reaches the temperature of crystallization along the edges first.*

Q: Where would you find magmas cooling very rapidly? What would you predict about the shapes of the crystals?

A: *Lava, which is magma that erupts at the surface of the Earth, cools very rapidly because the magma cools from temperatures as high as 1,000°C to roughly 25°C in a matter of hours or days. The resulting crystals in lavas are generally very small. Close examination of a lava flow reveals that the top and bottom of the flow generally contain the smallest crystals, and that the middle of the flow contains crystals slightly larger—much as was observed on the glass slide. The radial pattern of crystals seen in the experiment is identical in texture to spherulites that form in hot volcanic glass, or obsidian.*

EXPERIMENT 2

Crystal Growth by Cooling Solutions

(simulates formation of hydrothermal veins)

Needed:

- Two glass beakers (1,000-ml size works best)
- About 500 g of rock salt (coarse salt, salt blocks from livestock feed stores, and pickling salt all work better than table salt)
- Hot water

Procedure:

Dissolve the salt into a beaker of very hot water or heat the salt plus water on a hotplate, stirring well as the salt dissolves. Add salt until the solution is clearly saturated, and a layer of salt settles to the bottom. Pour some of the solution off to the second beaker, being careful not to get any of the undissolved salt crystals with it. Let this clear liquid cool to room temperature, or place on a cold metal surface to enhance the rate of cooling. Crystals should begin to form.

Representation:

Salt, like most other common minerals, becomes increasingly soluble as the temperature of surrounding liquid rises. Conversely, as a hot solution moves into rock fractures it cools and begins precipitating the dissolved minerals. As quartz and calcite are common soluble minerals, their crystals often line fractures.

Natural Examples:

Veins filled with quartz (as in McCurtain County) and calcite (in the Arbuckle Mountains) are common products of cooling solutions. Small calcite-filled veins can be seen in rock exposures along I-35 in the Arbuckles. Collecting trips for vein quartz in southeastern Oklahoma can be arranged with some property owners.

Questions for discussion:

Q: Hot salty water is a good solvent for minerals. What is a solvent?

*The teacher can use the questions as class discussion after completing the experiments—or as group or individual student reports to be written after the experiments.

A: *A solvent is a fluid, usually a liquid, with the capacity to dissolve substantial quantities of some other substance, usually a solid solute.*

Q: Ground water cools as it rises toward the surface, so the temperature within the Earth must increase with depth—as one goes down. What heats the Earth from the inside outward?

A: *The Earth is heated from within by decay of naturally radioactive isotopes of elements including U (uranium), Th (thorium), and K (potassium). These elements give off heat as their atoms split or decay, as in a nuclear reactor.*

EXPERIMENT 3

Crystal Growth by Evaporation

(simulates formation of evaporite minerals)

Needed:

- Two glass beakers (1,000-ml size works best)
- About 2 kg of epsom salt or refined white suger
- Hot water
- Cheesecloth or other loosely woven cloth—about a foot square.

Procedure:

Dissolve the epsom salt or sugar into a beaker of very hot water, stirring well as the salt dissolves. Add epsom salt or sugar until the solution is clearly saturated, and a layer of epsom salt or sugar settles to the bottom. Let the solution stand until it has cooled to room temperature. Pour some of the solution off to the second beaker, being careful not to get any of the undissolved salt or sugar crystals with it. Cover the second beaker with the porous cloth and let it stand in an open room with good ventilation, but not in sunlight or a draft. Through evaporation, crystals of epsomite or sugar will grow in the solution. Note: epsomite forms clear, colorless crystals that turn white when exposed to air. If rough bamboo grilling skewers are placed in the solution from the start, then crystals tend to form on those skewers, and they can be removed easily, inspected, and placed back in the solution for continued growth.

> *CAUTION:* Epsomite acts as a strong laxative if ingested. The sugar crystals, however, are "rock candy" that can be eaten.

Representation:

Evaporites are mineral deposits formed by evaporation of water from solutions rich in dissolved ions. As the water evaporates, the concentration of the dissolved ions increases until a saturation level is surpassed and evaporite minerals begin to form.

Natural Examples:

In Oklahoma, the gypsum crystals found in the Salt Plains Wildlife Refuge, near Jet in Alfalfa County, form by evaporation of calcium- and sulfate-rich ground water just below the surface.

Questions for discussion:

Q: What happens to gypsum crystals in the sediments of the Great Salt Plains after a rainstorm?

A: *The gypsum crystals dissolve, because rain that soaks into the ground is undersaturated with respect to gypsum. That is, fresh rainwater can dissolve gypsum, much like the water in the beaker originally dissolved the salt. As this rainwater then began to evaporate, the concentration of dissolved gypsum would increase in the water, until a saturation level is surpassed and new gypsum crystals begin to form, completing the cycle.*

Q: Why do gypsum crystals in sediments of the Great Salt Plains contain an hourglass pattern of sand inclusions?

A: *The gypsum crystals grow around grains of the sand that fills the basin of the Great Salt Plains. The gypsum crystals grow fast along their long dimension—too fast to push the sand grains out of the way of the growing crystal. Instead, the crystal grows more easily around the sand grains and includes them in the crystal (this is also the way barite roses get their sandy, red color). In the short dimension, the gypsum crystal grows more slowly and can physically push away the surrounding sand, leaving the crystal clear in this direction.*

EXPERIMENT 4

Crystal Growth by Mixing

(simulates chemical reactions in sediments and metamorphic rocks)

Needed:

- Two small (200 ml) glass beakers or plastic solution bottles
- One graduated cylinder (100 ml)
- About 10 g of epsom salt
- About 5 g of barium chloride (from a scientific supply house)
- Distilled water, at room temperature
- Disposable plastic dropper

Procedure:

Dissolve the epsom salt and barium chloride separately into two beakers or plastic solution bottles. Tap water is okay for the epsom salt, but the barium chloride requires distilled water. The solutions need not be saturated. With the dropper, drip barium-chloride solution slowly into the epsom-salt solution. Milky white clouds of the mineral barite will form, and, given time, will settle to the bottom of the beaker.

> *CAUTION:* Health effects of barium chloride are not fully known, but evidently inhaled $BaCl_2$ dust can cause serious respiratory damage, and ingested solutions are toxic to the heart, nerves, kidneys, and digestive system. Protective gloves and a suitable dust mask are recommended during preparation of solutions. This exercise is not suitable for students who may inadvertently ingest the solution.

Representation:

Many reactions that precipitate minerals in metamorphic and sedimentary rocks occur by mixing solutions (such as ground water) with different chemical properties (solutes, pH, oxidation state, etc.). Mixing occurs, for example, when ground water from one rock flows into another and mixes with its fluids. If the two rock types are very different, their ground-water content is likely to differ chemically as well, and upon mixing a reaction may dissolve or precipitate minerals. This type of mixing experiment illustrates "salting out," in which a reaction among soluble components produces another compound with very low solubility.

In this demonstration the reaction forms barite ($BaSO_4$):

$$BaCl_2 + MgSO_4 = BaSO_4 + MgCl_2$$

Natural Examples:

Barite roses, the state rock of Oklahoma, may originate in some type of mixing reaction. The host for the barite roses is the Garber Sandstone, a good aquifer and therefore both porous and permeable. One hypothesis holds that ground water from chemically different sources flowed into the Garber, mixed, and locally deposited barite in the pore spaces of the sandstone. Another possibility is that reduced (oxygen-poor) ground water containing both barium and reduced sulfur (i.e., H_2S) mixed with oxidizing water near the surface, and oxidation of sulfides to sulfates triggered precipitation of barite.

State Rock of Oklahoma, the barite rose.

Question for discussion:

Q: How could you find whether your drinking water contains sulfate?

A: *It takes very little sulfate to cause barite to precipitate when $BaCl_2$ or its solution is added to water. You can detect sulfate in your drinking water by adding a few drops of the $BaCl_2$ solution (made with distilled water!) and watching for cloudiness or milkiness in the drinking water. If the water turns cloudy, it contains sulfate.*

EXPERIMENT 5

Charged Surfaces of Crystals

(demonstrates the crystals possess unsatisfied electrical charge on their surfaces)

Needed:

- Glass rod, about 1 cm thick and 20 cm long
- Wool fabric or rubber sheet
- About 10 g finely milled cosmetic mica (though milled clay such as kaolinite might work)
- Plastic wrap or mylar sheet, about 10 × 10 cm

Procedure:

Place a small quantity (about the volume of a dime or quarter) of finely milled muscovite mica (the consistency of face powder) on a sheet of plastic wrap or Mylar sheet. Rub a glass rod (plastic rod works but not so well) with wool, felt, or (if the weather is right) merely walk along a carpeted floor in rubber-soled shoes to build up a static charge on your body that will be transferred to the glass rod. Approach the glass rod to the milled mica without touching it. If your mica is very fine-grained and if you can build up a charge on the glass rod, you will see the mica jump to the rod at a distance of about 1 cm, and the mica will cling to the rod.

Application:

The perfect cleavage of mica exposes planes that are dominated by one type of atom, either oxygen (negative charge) or potassium (positive charge). Hence the overall surface acquires an electrical charge (+ or –) great enough to overcome gravity and lift the mica grains toward an oppositely charged glass or plastic rod.

EXPERIMENT 6

Crystal Dissolution

(demonstrates that dissolution and growth initiates on the corners of a crystal)

Needed:

- One small (200 ml) glass beaker
- About 10 g of coarse rock salt
- Hot tap water

Procedure:

Fill a small glass beaker or jar (200 ml) one-third full of tap water and heat to steaming but not boiling on a hotplate. Add a sharp cleavage fragment of halite (obtained by breaking a chunk of block salt for cattle)—about 1 cm on a side. Let the liquid stand 5 to 10 minutes, or until the cleavage fragment shows rounding on its corners and edges. Remove it from the solution with tongs and place it next to a fresh piece of halite.

Application:

The halite fragment, which was a sharply defined rectangular solid when first cleaved, becomes smoothly rounded especially at the corners and edges. If the dissolving cleavage fragment is observed for a time in the hot water, it will be seen to dissolve first at the corners, then at the edges; if dissolved rapidly, it will approach the shape of a sphere. The demonstration illustrates that the corners of crystals are the most energetic sites on the surface, and the most prone to grow or, in this case, to dissolve.

Fossils to Fuel: An Elementary Earth-Science Curriculum

Mindy Stitt
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INTRODUCTION

This is a synopsis of a curriculum and activities developed by the Oklahoma Energy Resources Board, the Oklahoma Department of Education, and State educators. The activities provided by the OERB were designed to teach students about fossils fuels through discovery, hands-on investigation, and open-ended questions.

Fossils to Fuel is an earth-science curriculum, a six-week program complete with a teacher's guide and activities kit. It was developed in 1996 by a team of OERB representatives, elementary-science educators, university curriculum specialists, and geologists; in spring 1997 it was tested in classrooms by more than 40 Oklahoma teachers.

The program was designed to help elementary students learn basic concepts about how energy from the Sun is transformed into carbon-based matter and then into petroleum, and ultimately into matter and energy for use in everyday life. Through training in use of this new energy curriculum, elementary educators throughout Oklahoma are better prepared to teach—competently and confidently—energy concepts relating to oil and natural gas.

Though *Fossils to Fuel* is not discussed here in its entirety, the curriculum as a whole assists educators in teaching concepts relating to science, and also to math, history, and economics. In this article, only two learning cycles are presented, but the interested reader can get more information, or a workshop schedule, by visiting the OERB's Web site at http://www.oerb.com or calling 1-800-664-1301. Oklahoma teachers can obtain the exercises by attending a day-long training session. Teachers leave the workshop with a teacher's guide and an activities kit. The workshops are free, and the OERB reimburses school districts for substitute pay so that teachers can attend the training. If a workshop is held on a Saturday, the OERB pays a $25 stipend for attending.

What Is Energy?

The world is full of things in motion. Birds fly through the air, trees move in the wind, and ships sail on the sea. People, animals, and machinery all require a source of energy. The energy that turns the blades of a windmill comes from wind. The amount of work done by the mill depends on how hard the wind blows. Fuel from petroleum yields the energy that planes use to fly. Some boats use fuel to power their engines; others rely on wind to fill their sails. The energy that moves a car comes from gasoline burned in its engine. The Sun provides the energy that produces the food you eat, and therefore the muscle power used in pedaling your bike.

Where Does Energy Come From?

All energy in the examples above originates in the Sun. Without the Sun, there would be no life on Earth: its light is transformed into many sources of energy we use every day. Important sources of energy are fossil fuels—notably oil, natural gas, and coal. By processing fossil fuels at power stations, we convert their stored energy to electricity, and thus we can use energy from the Sun.

How Are Oil, Natural Gas, and Coal Formed?

Millions of years ago, many present-day land areas were covered by seas filled with billions of tiny plants and animals. As these plants and animals died, their remains sank to the sea floor and were buried in layers of clay, sand, and other sediment. As time passed, heat and pressure worked on the buried remains until they became fossil fuels trapped in rock. If the rock is porous, it can hold oil and natural gas; if it is permeable, the oil and gas can be extracted—pumped out of the rock.

For more than 150 years, mankind has been exploring for petroleum and extracting it from the Earth (coal has been used for millenniums longer). When we use the 6,000 or so products made from fossil fuels today, we are releasing energy that first came to Earth from the Sun millions of years ago.

How Do We Find Oil and Natural Gas?

In 1859, near Titusville, Pennsylvania, Edwin L. Drake became the first person to drill successfully for oil. His strike set an example for many others, and by 1900 the oil fever had spread to many states, and especially to Oklahoma and Texas. Since then, prospecting has turned into a science using computers, satellites, and seismographs to search in rock strata under dry land and also beneath the ocean floor.

Long before drilling can begin, geologists and geophysicists gather clues about rock formations and rock structures that can hold oil and natural gas. They look in many places and use many tools, examining geologic maps and aerial photographs, studying microfossils, and measuring sound waves echoed from rock strata deep below the land surface. After they have settled on a promising site, and property rights have been obtained, drilling can begin. But that isn't all.

For decades, petroleum companies have devoted a great deal of time and money to controlling the impact of drilling and production on the environment. Today, U.S. companies spend more money on protecting the environment than on drilling. Whether onshore or offshore, drilling tracts must be intensively studied, and all effects carefully predicted.

During drilling, blowout preventers are used to avoid re-enactment of the exciting but wasteful and destructive gushers of the early days. Steel casing is set and cemented in the borehole to protect ground water from contamination. The welfare of crops, wildlife, and humans is always kept in mind. Even so, it is a question of balance between the need for energy and the need for an undisturbed environment. Industry, government, and citizens must cooperate to achieve the balance.

How Is Petroleum Transported and Used?

After petroleum is produced, it still must be transported safely for processing and use. Oil can be moved to refineries by truck, pipeline, or ship, but natural gas in large quantity must be sent through high-pressure pipelines. Consequently, natural gas produced in the U.S. can be used only on this continent. Crude oil can be shipped anywhere on Earth for use—according to one estimate—in more than 500,000 ways.

LEARNING CYCLES

The program *Fossils to Fuel* introduces students to a variety of learning cycles, each beginning with an open-ended "Wonder Why" question (step 1 of the learning cycle). The question encourages students to focus on the concept to be discovered, and to communicate as well as listen. Often, misconceptions are revealed and can be dealt with in the second step of the learning cycle, "Discovery," in which students learn through lab experiments.

Step three of the learning cycle is "Concept Formation," which leads students to discuss their findings, and thus rebuild or refine the concept. Once they understand the concept, "Application/Expansion" begins, and they apply their new information to a new situation. This brings about a real-world association, and closes the series.

ACTIVITIES

The exercises outlined below are drawn from cycles compiled for the *Fossils to Fuel* teacher's guide.

Seeping Stones

Wonder Why... You have probably heard someone say "solid as a rock." Do you think rocks are entirely solid—that is, non-porous and impermeable? Or do they have open spaces inside?

Concepts

Some rocks are porous and permeable: they have interconnected pores that allow liquid, like water or oil, to flow from one pore to another.

Materials

- 5 rock samples collected by each group of students.
- Other samples of rock, such as limestone, sandstone, shale, and granite, provided by the teacher.
- An eyedropper or pipette for each group of students.
- Water.
- Paper towels.

Discovery Procedure

1. Each group is to collect 5 different kinds of rock from home or the school area.

2. The teacher is to provide samples of sandstone, limestone, shale, and granite, so that each group will have 7 to 9 rocks.

3. Next, the teacher asks the groups to predict (and to write down) what they think will happen when 5 drops of water are dripped onto each rock (Fig. 1).

4. Discussion.

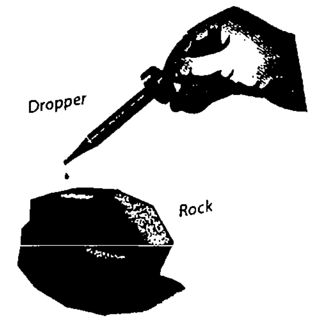


Figure 1. Water dripped onto rock specimen.

Concept Formation

1. What happens to the water? Find what is different about the rocks that absorbed water.

2. What happens to water that was not absorbed? Why did some rocks absorb water while others repelled it?

3. Where did the absorbed water go when it disappeared? Here the teacher should introduce the concept of permeability—the capacity of a rock to let a liquid, like oil or water, flow from pore to pore (for example, a bath sponge is permeable material). See Figure 2, and sketch another example.

4. Demonstration by the teacher: Use a clear plastic cup full of marbles or rocks. Ask: "If I add water to this container, how much water do you say it will hold?" Using a graduated cylinder, measure 100 ml of water, and pour 20 ml of the water into the cup. Ask students how much water you should add to fill the cup. Keep going until the cup is full. How does this demonstrate permeability? Where does the water collect?

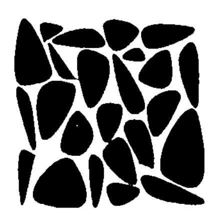
5. Can rock store anything other than water? Pores in rock may also hold oil and natural gas. If the pores are connected, the rock is permeable, and the permeability allows oil and natural gas to flow from one pore to another. The more permeable the rock, the easier it is to produce oil and gas (assuming that oil or gas are present).

Vocabulary

permeability—Liquid or gas can flow through a permeable material because its pores are connected.

impermeability—Flow is impossible, because the pores are not connected.

Figure 2. Schematic diagram showing interconnected pores (white space) in a rock. Black areas represent grains of minerals that make up the rock.



Application/Expansion

- Using the data collected so far, think about what will happen when 10 drops of water are used. Test your idea.
- Predict which rocks will hold the most water. Line up the rocks from the least permeable to the most permeable. Chart and graph the number of water drops absorbed by each rock. Use a core sample (from the teacher's kit) to compare its absorbency with that of other rocks.
- Compare your rocks to a rice cake, a sponge, and the pores in your skin. How are they alike or different? How does sweat leave your body? How do liquids or gases leave rocks?
- Build models of sedimentary rock, using various materials.
- Construct a chart of foods that are permeable and impermeable. For an example, see Figure 3.

Permeable	Impermeable
Cake	Flavored gelatin
Cornbread	Hard Candy
Rice Cake	Hershey Chocolate Bar

Figure 3. Examples of foods that are permeable or impermeable.

Teacher Information

Some sedimentary rocks are porous, like a sponge. In sandstone, grains of sand are held together by mineral cement, created by pressure, time, and mineralizing solutions.

Oil and natural gas form from decayed plant and animal material. Over time, layers of sand and other sediments are compacted into sedimentary rock. Tiny spaces, or pores, between the particles of rock enable the rock to hold liquid. Oil and natural gas may become trapped in the pores. Pores may be interconnected to form passages. Rocks with interconnected pores are permeable. Permeability means that liquid or gas can move through the rock via the interconnected pores. If a rock has pores, but the pores are not interconnected, then liquid cannot flow through the rock—it is porous but impermeable.

Oil and natural gas are extracted from inside permeable rock. This is contrary to a common belief that oil occurs as pools in caverns. However, oil does sometimes—not often!—occur in natural caverns in limestone. And petroleum geologists do call some oil fields "pools"—a convenient term, if fanciful.

Let's Rock

Wonder Why . . . Geologists looking for petroleum must locate permeable rocks that may contain oil or natural gas. Have you ever wondered how they search?

Concept

Geologists use sound waves to identify natural underground geologic structures that may contain oil or gas. Sound waves travel at different speeds through different kinds of rock, and measuring travel time tells experts much about the rocks.

Materials

- 1 metal dinner fork for each group of students.
- 100 cm of string.
- Samples of a variety of rock types.

Discovery Procedure

1. Tie the fork at the center of the string, just above the prongs (Fig. 4).
2. Wrap the ends of the string around your forefingers, and press your fingers gently to your ears.
3. Lean forward till the fork hangs free (think of a stethoscope).
4. Gently swing the fork against a variety of objects around the room.
5. Ask a partner to strike the prongs of the fork, gently, with a variety of rocks.
6. Note the different sounds produced by different objects.

Figure 4. Diagram showing use of fork and string in experiment.

Concept Formation

1. Why do different objects produce different sounds?
2. Ask students to discuss the differences.
3. How could scientists use information like that to map rock layers hundreds or thousands of feet below the land surface?

Application/Expansion

- Create a list of different jobs—or careers—in petroleum exploration.

Teacher Information

Sound waves travel at different speeds through different kinds of rock. In seismic technology, sound waves created by explosives detonated at the surface or underground are recorded by seismographs (seismographs are best known for recording earthquakes). Reflected sound waves are received by geophones, which transmit the sound waves to a seismograph in a truck. The rates at which the sound waves are reflected back create a picture of the subsurface geology.

That information is in turn interpreted by geologists and geophysicists to identify the rock layers and their properties such as porosity and permeability. Even after the seismic picture is analyzed, the presence of oil or natural gas is never guaranteed. Analysis only shows whether a stratum *can* hold oil; proof awaits the drill bit.

Conducting Earth-Science and Rockhound Programs in Secondary Schools

John Charbonneau
Stillwater Mineral and Gem Society
Stillwater, Oklahoma

While serving in the United States Army, I traveled to many countries and attended several colleges where I majored in geology, and got hooked on rocks, minerals, and fossils. That led me to teach many classes while in the military, and to realize the importance of educating our young people.

When asked by the Oklahoma Geological Survey to give a presentation on "How rockhounds can be of assistance to teachers," I was extremely pleased and excited—pleased because the Stillwater Mineral and Gem Society, and especially its Education Team, is doing well. We are creating an interest in our hobby, at the same time educating more people in earth science, and obviously the word has gotten out. I was excited because our Education Team truly enjoys assisting teachers by describing our experiences and by contributing teaching aids for the education of our future scientists, geologists, teachers, and, in short, inquisitive and wondering young minds.

After my initial excitement, it dawned on me that I had never put pen to paper nor taught anyone the basic steps in preparing our educational events. Nor had I told how we made up the many samples we have used in our presentations and given to schools, libraries, and U.S. and foreign clubs. So I had to reach back into my recollection of the Team's varied activities during the 10 years I have been with the Stillwater Club, bring forth the steps we had taken in preparing for them, and organize those steps. To sum up our work: we found a specific educational need, and we came up with the right way to address this need by using our knowledge garnered through the years.

I. Among our club's accomplishments:
   a. Preparing displays and demonstrations for local, county, and state fairs.
   b. Constructing library displays.
   c. Donating books to libraries, classrooms, and organizations.
   d. Donating specimens—individual samples, cards, sets, or boxes—to classrooms and organizations. (We have sister-city schools in Europe, South America, and Japan.)
   e. Holding hobby presentations for new arrivals in the community, city, and local colleges.
   f. Hosting educational field trips.

II. Rockhound clubs generally use one or more of three assets:
   a. Material objects—Rockhounds have samples of rocks, minerals, and fossils that can be used for teaching aids; they go on field trips, locally and regionally, and swap with other clubs, and therefore have a greater variety of specimens that can be brought to the classroom; specimens larger than the ¾-inch size found in most school sets enhance the students' ability to identify fossils in the field.
   b. Experience—Many rockhounds have background (education or working) in geology, engineering, oil discovery, meteorology, space exploration, and road construction. Most of all, they have knowledge gained by visiting collection sites. They have observed the lay of the land and rock formations. Most teachers call on parents, local business people, and retirees to pass on their wealth of experience and to serve as role models. Also, most members and clubs have extensive libraries—books, videos, and slides—and have access to libraries of the American Federation of Mineralogical Societies, the old U.S. Bureau of Mines, and the state geological surveys.
   c. Methods—Clubs use various means to raise money for books and materials needed in constructing displays for classrooms and libraries. They sell specimens in grab-bags, auction off collections of retired or deceased members, and receive direct donations from members and their families; the money also goes to scholarship funds of the American Federation of Mineralogical Societies and the regional federations.

III. Problems and resources:
   a. Not all clubs are equal in money, equipment, and number of members knowledgeable about geology, rocks, minerals, and fossils. But nearly every club does have an education committee, and every club does have pride. They all wish in some manner to pass on their love of the hobby to others.
   b. We have very few restrictions as to how we can assist teachers. However, teachers and students do outnumber rockhounds, and at times we are forced to prioritize our commitments; we need several possible dates for a program. At times we have been forced to say "no," but that is very rare!
   c. Last is the relationship with teachers and the money available. Most club teaching teams go to the schools, thereby saving time for transporting students and giving teachers more time to prepare for classes. As these rockhounds are giving their time, it is best to use them fully and to incorporate other subjects. Teachers can organize several earth-science classes by a round-robin method, teaching first one subject, then another. For example, when teaching about plants and animals outdoors, a teacher can add rocks, minerals, and fossils to the list of subjects.

Table 1. — Oklahoma Rock Clubs and Meeting Places (2001)

Ada Hardrock & Fossil Club
Box 51
Mill Creek, OK 74856
Meets second Thursday at 7:00 p.m.
Ada Public Library
124 S. Rennie
Contact: Bill Lyon, (580) 332-8666

Enid Gem & Mineral Club
2614 West Oklahoma Ave.
Enid, OK 73703
Meets first Thursday at 7:30 p.m.
Hoover Building at Fairgrounds
314 E. Oxford
Contact: Frances Johnson, (580) 233-1852

McCurtain County Gem & Mineral Club
405 S.E. Avenue G
Idabel, OK 74745
Meets third Tuesday at 7:30 p.m.
Public Library
Contact: Doris Perkins, (580) 286-3133, email: dperkins@pinenet.com

Mount Scott Gem & Mineral Society
44 N.W. 29th Street
Lawton, OK 73505
Meets fourth Friday at 7:00 p.m.
Town Hall
5th Street and B Avenue
Contact: Jim Williams, (580) 357-6665

Oklahoma Mineral & Gem Society
P.O. Box 376
Oklahoma City, OK 73101
Meets third Thursday at 7:30 p.m.
Will Rogers Garden Center
3400 N.W. 36th Street
Contact: Joyce McBryde, (405) 677-6723

Osage Hills Gem & Mineral Society
P.O. Box 561
Bartlesville, OK 74005
Meets third Thursday at 7:00 p.m.
East Bartlesville Christian Church
3221 East Tuxedo Boulevard
Contact: Jody Adams, (918) 336-6439

Rough and Tumbled Rock & Gem Club
129 Viola Street
Ponca City, OK 74601
Meets fourth Tuesday at 7:00 p.m.
102 North First Street
Contact: Jay Bowman, (580) 765-5854

Shawnee Gem & Mineral Club
111 West Hickory
Shawnee, OK 74804
Meets first Tuesday at 7:30 p.m.
Northridge Church of Christ
1001 East MacArthur
Contact: Tom Morris, (405) 386-2314, email: tomor@mcloudteleco.com

Stillwater Mineral & Gem Society
1116 South Gray Street
Stillwater, OK 74074
Meets fourth Thursday at 7:30 p.m.
First United Methodist Church
7th and Duck Streets
Contact: Dan and Ruby Lingelbach, (405) 372-8635

Tahlequah Rock & Mineral Society
P.O. Box 932
Tahlequah, OK 74465
Meets third Tuesday at 7:00 p.m.
Public Library
Contact: Betty Ruth Adams, (918) 456-4754, email: bradams@ipa.net

Tulsa Rock & Mineral Club
P.O. Box 2292
Tulsa, OK 74101
Meets second Monday at 7:00 p.m.
Tulsa City-County Library
400 Civic Center
Contact: Linda Jaeger, (918) 481-0249

Teachers and rockhounds can devote one day to "History of Our Local Area." They can involve members of the local historical society, a museum or private collection (such as railroad locomotives, bicycles, farm machinery), and a local rockhound club to deal with geologic history and resources. In Stillwater, one school has worked with small towns and their history (gunfighters, oil, famous citizens, and athletes). The school asked the historical society if it would hold a history walkabout; if there was an old graveyard nearby where the children could make rubbings of the tombstones of historical figures; whether the students could visit a local museum or collections of memorabilia. And then the local rockhounds hosted a fossil dig, where students were to find and identify at least five fossils each.

Oklahoma is rich in history and scientific resources; teachers need not be restricted to the zoos or science centers of Oklahoma City and Tulsa. The only limit is the individual's will to search for that which is new and different, or for an innovative method of teaching.

Table 1 lists rock clubs for Oklahomans, places where they meet, and names and phone numbers. Each club has a list of all other Oklahoma clubs and also the clubs elsewhere in our Rocky Mountain Federation—the largest in the American Federation of Mineralogical Societies. Our federation covers Arizona, Arkansas, Colorado, Kansas, Nebraska, New Mexico, North and South Dakota, Oklahoma, Texas, Utah, and Wyoming. This information is handy during vacation and when planning field trips in other states. However, not all clubs have an abundance of retirees with the ability to teach and with time available during weekdays. Also note that due to high insurance costs, caused by the propensity for legal action versus responsibility for one's self, field trips are becoming more difficult for clubs to sponsor.

Fossil Collecting and Cleaning

John C. Osborne (deceased)
Stillwater Mineral and Gem Society
Stillwater, Oklahoma

INTRODUCTION

This article is meant to further amateur fossil collecting in a safe and mannerly fashion. To this end, there are two very important rules we must never forget! Remember the Code of Ethics by the American Federation of Mineralogical Societies. Respect and follow it. And do not clean out a site; leave some fossils for others. I wish to thank the members of the Stillwater Mineral and Gem Society and all the other rockhound clubs and their members who have so graciously helped me in furthering my knowledge and collection of fossils.

FIELD EQUIPMENT

It is necessary to prepare for fossil collecting by obtaining the proper equipment, for yourself and for your car or truck.

For Hunting and Collecting

- Rock hammer or ball-peen hammer.
- Chisels, screwdrivers, pry-bars.
- Ice pick or knife.
- Soft paintbrush (to brush dirt and dust from rocks and fossils).
- Notebook for notes, and pen or pencil.
- Plastic sandwich bags, and newspaper for wrapping and protecting finds.
- Backpack, boxes, gallon jugs, nail apron.
- Handbook for identifying fossils.

For Yourself

- Water
- Lunch
- Insect spray
- First-aid kit
- Camera
- Proper clothing (tough shoes and gloves)
- Headgear (hard hat, cap, goggles)

For Car or Truck

- Fuel
- Water
- Oil
- Spare tire
- Tools

In remote areas, take along extra gas, water, oil, and fan belts; a CB radio or cell phone is essential.

Other Planning

Maps—Road maps, general-purpose maps, topographic maps (I like 1:100,000-scale topographic maps, which show a large area and also road and contours).

Permission—Always get permission to enter private property; call each time you go, even though you already have permission.

Safety—Watch where you step and where you reach (look out for snakes and loose rocks). Always turn rocks over carefully (look for spiders and scorpions). Do not leave trash (even glass bottles can cause fires). Tell someone (such as the police or a friend) where you are going and the approximate time you will be back. When you return, tell them; you don't want them running all over the place looking for you without good reason.

FOSSIL COLLECTING MY WAY

I always carry a canvas tote bag in the trunk of my car. It contains rock hammers, a ball-peen hammer, a short-handled sledge, large and small screwdrivers, large and small chisels, an ice pick, several knives, a hand trowel, and a four-prong garden digger. I leave the bag in the car trunk with only the tools I need in the field. To carry equipment from my car to the collection site I use a canvas backpack that is always ready to go. The small pocket contains sandwich baggies, notebook, marker pen, first-aid kit, tissue paper, and a shoestring for use as a tourniquet. When collecting small fossils that have weathered out I take a nail apron.

If I plan to be at a remote site all day, I add a Thermos bottle of coffee, water (in a plastic 20-ounce bottle), and lunch. My hammers have shoestrings looped through the holes in the handles so I can hang them from my belt or wrist. I carry my lunch in a paper bag that I can fold up in my pocket (bulkier containers take up too much room). In warm weather, I spray on bug repellent before leaving the car. When hunting in a hard-rock area, I take my rock hammer, chisels, gloves, and goggles. In soft limestone, I take my rock hammer and ice pick or screwdriver (for prying). In quarries, I take my hard hat, goggles, and gloves.

At the site, I find a spot to set my backpack, and then wear my nail apron and carry my hammer. The other tools are still within reach.

If I find a delicate fossil, I wrap it in tissue and put it in a baggie. Paper towels are useful too; several, folded up, fit in a pocket.

If I find a fossil that is large and broken, I carefully clean the dirt and debris off it, then number each piece on both sides of the break (1-1, 2-2, 3-3) for reassembly at home.

Each piece is individually wrapped. If it is too crumbly to move, I cover it and mark the spot with glue or plaster of paris for recovery later. If the find seems especially important, I may take photographs and notify an expert who can remove it without damage. (I once walked away from a nice spirifer because I didn't have the proper tools to remove it at the time. I'll go back some day; it'll still be there.)

If you find a large fossil and cannot remove it, please don't break it up! If you do, it'll be no good to anyone.

If I find fossils in matrix, I trim off as much as I feel is safe but I don't trim too close. That could damage the fossil. Some fossils can be found only by splitting open the rock; it's the only way to find the spiny trilobites. I take all pieces home and use Super Glue to put them back together. Such specimens generally should be cleaned by a professional with a sandblaster.

I put the fossils in my backpack and carry my hammers and Thermos back to the car. There I wrap the fossils in newspaper and put them in boxes or flats to take home.

In my notebook I write down exactly where I found the best specimen, and, if it's a new site, I give the directions to it. Back home, I mark the spot on a topographic map or road map.

CLEANING FOSSILS

In my back yard at home, I wash the larger fossils with water and a toothbrush. The smaller ones are washed at the kitchen sink and laid out on paper towels to dry, and then sorted; the nicest ones are cleaned right away, whereas the others are bagged with a piece of paper showing date, location, and age. Their cleaning comes later.

Some fossils, such as brachiopods, go into a solution of water and vinegar (10:1) to soak for a day or two. I keep checking them, and when the vinegar stops bubbling I remove the fossils, wash them with plain water, and let them dry. Remove the cleaned ones and put the others back in the solution. I keep an eye on them, because the acid will eventually attack the shell, pit them, and give the surface a powdery look.

Cleaning vertebrate fossils with vinegar calls for extreme care; the bones can become soft and fall apart at the slightest touch. Lizard and snake bones from Richard's Spur, near Lawton, behave this way.

If a fossil bears only a little matrix, I clean it by hand. Some I can clean with a utility knife and an X-acto knife with a #11 blade; I just scrape the matrix off. I always use a dark-brown towel as a background, and wipe off the blades with a folded paper towel. First I dip the fossil into water to soften the matrix; that also makes the fossil lighter and the matrix darker.

I clean the fossil several times with water and toothbrush during scraping—that helps spot small indents filled with matrix. Sometimes I leave part of the matrix, which can enhance patterns such as growth lines.

I use a ball and needle to clean grooves and remove matrix faster. If the matrix is thick (1⁄16 to ¼ inch), I use an electric etching tool. I make my own chisels and points with 1-inch Hilti nails (which are hardened for use as anchors in concrete), using a silicon-carbide grinder and an electric-drill motor. I chuck the pointed end in the drill and grind the head off the nail; then I grind the shank down to fit the etching tool.

I must be careful removing the nail because it can be very hot. I drop it in a can of water to cool quickly, thus retaining

Another World in Oklahoma

I have snorkeled and scuba dived a few times over the years, so I know what kind of world lies under the surface of the water. I like to snorkel or just wear a mask along the shore in farm ponds around north-central Oklahoma. The ponds are clear enough along the edges for sunlight to reach the bottom, so there's a lot of plants, algae, small fish, crayfish, turtles, and insects.

When I pick up a fossil that has weathered out of Pennsylvanian limestone, I then look out across the prairie and try to imagine this area as it once was—a vast shallow sea, filled with all kinds of strange and wonderful creatures.

In a small creek bottom just east of where I live, my wife, Wanetta, and I once found a shoreline in Pennsylvanian limestone. At the shoreline are wave marks, and two feet higher are molds of *Calamites*, a horsetail reed.

Standing on that shoreline and looking to the north and west, and thinking back 300 million years, I can almost hear the lapping of the water at my feet. What sounds would I hear? Maybe the hiss of a lizard from the marshes behind me, the hum of a giant dragonfly overhead, or just a gentle breeze rustling the rushes.

Stepping off the shore and snorkeling out to where the water is 20 to 40 feet deep, I might be standing in a forest of crinoids, their arms gently swaying to and fro as they search for food. Brachiopods snapping shut, and tiny trilobites crawling away from my feet to hide under the coral. Maybe, if I'm lucky, I'll see the shark *Petalopus* swim slowly by, looking for a snack (but I hope not me!).

Suddenly I'm back in the 21st century, standing under the hot Oklahoma sun, holding a stone or shell that once enclosed a living creature.

I wonder—will my bones be fossilized, and two or three hundred million years from now be picked up and pondered over by a being that has evolved from us? I doubt it. This old world has aged a little and is no longer violent enough to cover my bones deep or fast enough with silt and dirt to preserve them.

Maybe this article will survive.

— John C. Osborne

Note: These thoughts were inspired by Pauline Price, writing in the April 1996 issue of *Rocky Mountain Federation News.*

its temper. (When grinding, never let the nail turn blue.) After the nails have cooled, I resharpen the points and grind chisel points on some of them. The etching tool acts like a miniature jackhammer, and can remove matrix quite fast. I have learned not to push it; all that does is beat the point off the tool. I don't try to clean all the matrix from a fossil because it will mark the surface with tiny dots or lines. It can also chip out large chunks.

After the fossil has dried, I number it with a marker pen (extra fine) and fill out an index card. If the specimen looks better wet, then I spray on a light coat of artwork fixative; that darkens the fossil and doesn't reflect light.

A leaf imprint in a light-color rock looks good with a coat of varnish, but then it will reflect light. Thus varnish is not advisable for a specimen to be shown in competition, but dextrin (an adhesive and thickener) is acceptable for painting on a fossil imprint, or on any specimen in matrix.

My small fossils are stored in baggies, with the index number on a small piece of paper.

If I happen to break a fossil while cleaning it, I let it dry, put it back together with Super Glue gel, and finish cleaning it. One Hunton (Devonian) trilobite head I found at Clarita, in Coal County, was lying upside down on the rock. I cleaned out the inside, let it dry, then filled it with epoxy and let it dry for two days. Then I removed the rock from the other side and had a nice specimen. I have used wood putty with a few drops of oak-wood stain mixed in to repair a crinoid bulb damaged while being removed from the ground. It looked great!

This work requires a good light source and a magnifier of some sort. I use a fluorescent desk lamp and a visor with a 7× magnifying lens, and one with a 10× lens for fine work such as trilobites.

When working dry, like grinding, I use a dust mask. On large fossils that need trimming with a chisel I wear goggles and gloves. For cleaning matrix from some specimens, as at the center of an ammonite, I build a square box with 4-inch sides and put in 2 or 3 inches of sand. The fossil is set firmly in the sand, which absorbs the shock of the strikes and helps prevents breaking. I use a small ball-peen hammer and a small chisel, use light taps, and, above all, patience!

PREPARATION AND DISPLAY

Once the fossils have been collected, proper tools and materials are needed to clean and prepare the specimens for display.

- Head visor or magnifying glass.
- Water and toothbrush (in a peanut-butter jar).
- Electric etching tool.
- Dental picks.
- Upholstery needle and a 1-inch wood ball for a handle.
- Scraper—a small utility knife with blades. (I use an X-acto knife with #11 blades.)
- Water and vinegar (10:1 mixture).
- Silicon carbide grinding wheel (to remove matrix).
- Moto Tool and diamond bits and stones.
- Sandblaster (rather expensive).
- Epoxy glue (for repairing broken fossils).
- Super Glue, both liquid and gel (for repairing broken fossils).
- Dextrin and fixative (for enhancing); mix dextrin and water to the color of tea.

For the Record

You must catalog your collection and record all details about each specimen. Otherwise, several years from now you will have forgotten the details and your specimens will be merely curiosities with little or no scientific value. Record data on index cards, as in this example:

General ID	PY-0010 Brachiopod
Fossil name	*Orthostrophia strophomenoides*
Date found	12-28-95
Location	White Mound, Murray County, Oklahoma; NW¼NE¼ sec. 20, T. 2 S., R. 3 E.
Geologic age	Lower Devonian
Formation	Haragan Formation
Reference	*Field Guide to North American Fossils*

If you are inexperienced, always report an important find to an expert. Never break up a fossil; get help from someone with experience enough to help you recover it properly.

Storing and Displaying

Specimens must be properly stored for both preservation and easy retrieval, or for display in your home, office, or work area.

- Paper boxes
- Plastic boxes
- Drawers
- Magnifying boxes (for tiny fossils)
- Plastic bags (tagged or numbered)
- Cotton or tissue paper (for wrapping or cushioning in a box)
- Glass cases
- Shelves

Arrangement

- At random
- By taxonomy
- By geologic age

Tagging and Numbering

Number your fossils to correspond with your index cards. Use an indelible marker with a fine point. Mark the fossil itself, or tape a label to it. If the fossil is small or too nice to mark, wrap the label around it. If you store it in a box or sandwich bag, put the label inside. If you number the fossil, write it in an inconspicuous place. If the fossil is too dark for the number to show, apply a small patch of typist's correction fluid.

DIGGING DEEPER

The best places to find information are public libraries, colleges and universities, and state geological surveys. The Oklahoma Geological Survey will send you a free copy of its *List of Available Publications*; you then can buy bulletins, circulars, guidebooks, mineral reports, and many kinds of maps dealing with Oklahoma. You also can order photocopies of some publications that are out of print.

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Meteorites: Their Origin, Recognition, and Classification

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ORIGIN AND IMPORTANCE OF METEORITES

Early History

To provide a setting for discussion of meteorites, consider first our part of the Universe. This is the source of our meteorites, and humans have been interested in the sky since very early times. To further this interest they built Stonehenge in England and El Caracol at Chichen Itza in Mexico, carved large rock outcrops and erected special buildings at Machu Picchu in Peru, and drew on rocks spirals that are intersected by the Sun's rays at definite times at Chaco Canyon in New Mexico.

These ancient astronomers tried to understand the heavens, and recorded observations of heavenly movements to help regulate time in daily life. In the beginning, the Solar System was a widely dispersed dust cloud. This cloud probably had its origin in one or a series of large supernova explosions in the Milky Way galaxy, some 8.5 billion years ago. Individual planetary masses formed through condensation and coalescing of particles in the dust cloud. As particles came together by chance and formed groups, a gravitational field was established and increased in strength as more particles joined the growing planetary body. Electromagnetic fields helped attract more material.

Formation of the Solar System

Eventually, through the action of gravity and electromagnetic fields, the mass of coalesced particles (with heating and subsequent melting) became our Sun and a group of circling planets some 4.55 billion years ago. Numerous bodies, formed during the early stages of the Solar System, collected together by gravity, the larger masses growing at the expense of the smaller. Bodies down to the size of meteorites continued to impact the larger planets, forming craters and increasing their mass.

Most of the planets in our system have acquired satellites, some the size of small planets, that orbit the host. These satellites also were part of the early Solar System, some from its outer regions and some as parts of their host or other planets: a few could have come from other parts of the Galaxy. They vary considerably in size and shape, and most, like our Moon, have impact craters that suggest an active past. Since the very large explosions at the beginning, the Solar System has been relatively quiet, with perhaps one important exception:

An anomaly in this system of neatly orbiting planets and their satellites is a large group of fragments orbiting beyond the orbit of Mars. One scenario for their origin begins with a major collision: a rogue mass of almost planetary size collided with an existing planet in a spectacular explosion. Both were broken up completely into numerous pieces—the asteroids—almost all of which remained in the orbit of the impacted planet. The event took place shortly after the planet developed an iron-nickel core surrounded by a partly differentiated silicate-mineral shell, and was the latest really big event in the development of the Solar System.

In another explanation, many of the asteroids developed individually as accreted bodies during the early formation of the Solar System, but did not accrete into a single planet because of the large gravitational field of the nearby planet Jupiter. Many of them collided with each other or with the major planets. Eventually the region near the inner and outer planets was swept clear, leaving only those between the orbits of Mars and Jupiter. This explanation has been criticized in not handling well the amount of time needed for development of planets large enough to have a partly melted and differentiated mass with an iron-nickel core. The mass would have to have been broken up later to form iron-nickel and stony fragments in a wide range of sizes like those in the asteroid belt—ranging from dust to masses several hundred kilometers in diameter.

Position of the Planets

Currently the Solar System consists of nine planets—Mercury to Pluto—with rather circular orbits of progressively greater diameter outward from the Sun. However, comparison of the orbits (Table 1) shows a large gap between Mars and Jupiter. In 1766, J. D. Titius von Wittenburg, a German mathematician, developed a numerical sequence relating the orbits (Norton, 1994), and in 1772, J. E. Bode, a German astronomer, published what is now known as Bode's rule (often the Titius-Bode law), which uses the sequence of Titius to show that distances from the Sun to the orbits of the planets form an orderly mathematical progression.

Under Bode's rule, a planetary orbit is determined by multiplying a number from the series by the distance from the Sun to the Earth's orbit; that distance is the astronomer's astronomical unit, or A.U. Individual values in the series begin with 0 and 3 and thereafter double: 0, 3, 6, 12, 24, 48, 96. To each value in the series, 4 is added, and the sum is divided by 10 to get 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, etc.

Comparison of values obtained from Bode's rule with the actual orbits (Table 1) reveals a vacancy between Mars and Jupiter at 2.8 A.U.; however, this distance is occupied by the group of fragments that orbit the Sun in the asteroid belt. Some of the asteroids, as suggested above, may have resulted from the collision of a large rogue mass with a major planet that occupied this orbital position—the gap in Bode's sequence.

TABLE 1. — PLANETS: DESCRIPTION AND ORBITAL POSITION

Name	Mean distance from Sun (A.U.)*	DIA. (km)	Mass (kg)	Density (g/cm3)
Mercury	0.39	4,800	0.32×10^{21}	5.4
Venus	0.72	12,200	4.87×10^{21}	5.1
Earth	1.00	12,740	5.98×10^{21}	5.52
Moon		3,475	0.074×10^{21}	3.34
Mars	1.52	6,750	0.64×10^{21}	4.1
Asteroids	2.77	—	—	3.3?
Jupiter	5.2	138,000	1.90×10^{24}	1.33
Saturn	9.54	114,000	0.57×10^{24}	0.71
Uranus	19.38	48,000	87×10^{21}	1.55
Neptune	30.06	45,000	103×10^{21}	2.47
Pluto	39.5	6,000	?	3?

*A.U. = astronomical unit = distance from Earth to Sun—about 93 million miles.

Asteroids—A Source of Meteorites

As early as the beginning of the 19th century, it was suggested that the asteroid belt could be the source of meteorites. Further research has supported the idea, which is now accepted by most scientists. A few meteorites, though, have come from the inner planets or their moons as a result of asteroid impacts. The number of fragments occupying the asteroid belt is unknown, but some 4,000 have been observed and cataloged (Norton, 1994). Of course a large number of smaller bodies and pieces have escaped observation. The largest asteroids that have been identified (Ceres, Pallas, and Vesta) have a density of about 3, similar to that of the Moon; each has about 0.01% of the Moon's mass, and a diameter of some 760 km.

.Ages of Meteorites

Although most asteroids have circular orbits, some follow elliptical paths that cross the orbits of the Earth, Mars, and other planets. Eventually these asteroids may impact planets, but their number will be small compared to those early in the history of the Solar System. Many or most of the early ones have already impacted the planets or their moons, forming the numerous craters we observe today. Some will have their orbits changed by gravitational interaction with the Sun, planets, and moons. As a result, some will impact bodies of our Solar System in the future; a few will be devastating. As for the time of the fragmentation events that formed the asteroids and meteorites, cosmic-ray exposure ages of iron meteorites provide a suggestion. These ages indicate how long the objects have been in space and, therefore, suggest an age for the break-up of their parent planet. These ages range from 215 million to 2,250 million years, with possibly significant groups around 300 and 600 million years (Buchwald, 1975). Stones have much smaller cosmic-ray ages, 1–60 million years, with groups at about 5 million and 10–40 million years. The range in exposure ages suggests multiple impact events. Formation of the parent planet and the crystallization and cooling of the various meteorites occurred at the time of the formation of the Solar System, 4.55 billion years ago. This age of formation seems consistent for all meteorites tested so far. The terrestrial age, or time on Earth, for most meteorites is only a few hundred years, with the irons (consisting primarily of iron minerals) surviving much longer than the stones (dominantly silicate minerals) because of greater resistance to weathering. Meteorites from Antarctica have much larger terrestrial ages; from 10,000 to 90,000 years on Earth, with 30,000 to 60,000 years being the age most common.

Comets

Comets, with their large elliptical orbits and long orbital periods, are probably members of the Solar System and could be another source of meteorites. Although they spend most of their time in the outer reaches of the system, even beyond Neptune, many have orbits that bring them close to the Sun and the inner planets. Most are thought to have come from the Kuiper Comet Belt—beyond the orbit of Neptune—or from a broad area still farther out known as the Oort Comet Cloud. Comets have very cold nucleii composed of various frozen gases embedded with solid particles of iron and silicate minerals. Although much of their icy mass is lost during near passes to the Sun, the solid particles could form meteorites. If a comet exploded on impact or in the atmosphere of a planet, much of its mass—predominantly ices—would be lost by heating and evaporation. Only minor amounts of solid material would remain to indicate the impact or explosion site. However, comets may have been a major source of water in Earth's oceans.

One comet impact on Earth may have been the Tunguska event of June 30, 1908, in Siberia. More than a thousand square miles of trees were leveled by an explosion, but no crater nor meteoritic fragments have ever been found. Only a few microscopic spheres, once molten, indicate the former mass. Recently scientists have suggested a stony meteorite as a source for the Tunguska event, citing chemical data; but more research is needed to validate their conclusion. One cometary impact has been observed, on July 16–22, 1994, when the comet Shoemaker-Levy 9 struck Jupiter as series of fragments.

Meteorite Falls, Finds, and Craters

Falling meteorites have been observed both by human eye and by photographic means, such as occurred with the Lost City meteorite fall of 1970 in Cherokee County, Oklahoma. That event was photographed by a camera array installed for this purpose—by the Smithsonian Institution—as the Prairie Photographic network.

A meteorite is considered a "fall" when has been observed coming through the atmosphere; it may be seen to impact and found shortly afterward. In contrast, a "find" is a meteorite not observed falling and found only much later. A fall is exposed to the atmosphere for only a very short time after impact. Some falls rest on the surface; others are buried a few inches or a few feet down. Some finds also are found on the surface, or perhaps 10 or 15 feet down. Small masses are usually close to the surface; large masses form impact craters. Really large meteorites form explosion craters.

The size of an impact crater is closely related to the size of the impacting meteorite, whereas explosion craters are many times as large. The size of an explosion crater depends on the energy (size, composition, and velocity), trajectory, and the geology of the site. An impact crater may be a single feature, or one of a group; often it contains only a single meteorite, although it may have broken into pieces on impact. Explosion craters are usually surrounded by meteorite fragments that resulted from the explosion. Arizona Crater (also known as Meteor Crater or Barringer Crater), a good example of a single explosion crater, was formed 20,000 to 50,000 years ago. It is 600 feet deep and some 4,000 feet across, and was formed by an iron meteorite about 100 feet in diameter striking with perhaps 4 to 5 megatons of energy (Shoemaker, 1960).

Henbury Craters, a group of 13, resulted from a multiple crater explosion event that occurred less than 10,000 years ago near Alice Springs, Australia. Meteorites in space may be a single unit, or several pieces moving together. As they enter the atmosphere they may fragment and impact Earth as multiple pieces. Some larger masses explode in the atmosphere, producing hundreds of pieces that then impact Earth as a strewn field miles across. Identification of the collected fragments as a meteorite comes through recognition of surface structure and internal composition (see section on Recognition of Meteorites). Most finds on the Earth's surface have lost little mass through weathering, but those uncovered after long burial, especially iron meteorites, may be only a core of the original material, with 50% or more having been lost to alteration.

Numbers of Meteorites

Of the falls, stony meteorites make up some 95% of those recovered; irons make up only some 5% of the falls. Of all of the meteorites recovered as falls and finds, stones make up 70% of the total, and irons and stony-irons (a transition group) some 30%. The low percentage of stones among finds suggests major loss through weathering and erosion. The distribution as observed in falls probably more nearly represents normal abundance in space. A total of 2,784 meteorites have been recovered over the last 500 years, according to the 1985 catalog of meteorites by the British Museum (Graham, 1985); 959 are listed as falls, 1,727 as finds, and 98 as unclassified. Their total weight has been estimated at 500 tons.

Recently the total number of known meteorites has been increased dramatically by finds in Antarctica, where more than 17,808 specimens have been recovered in only a few field seasons. The area continues to yield so many specimens that compilation of statistics is difficult. How many of those specimens are from the same fall is hard to determine; in the 1985 British catalog, those from the same fall or find are counted as one. The present British Museum catalog (Grady, 2000) lists 22,507 meteorites, which includes the Antarctic specimens.

Buchwald (1975) has remarked that whereas one meteorite falls to Earth each day, only 5.5 are reported to scientists each year. Many are lost in the ocean or on the ice packs. Those that land on ice may be easily spotted, or they may be carried along with its flow and eventually accumulate over thousands of years at the flow's interruption or termination, as in Antarctica.

Temperatures of Meteorites

The temperature of meteorites in space can be estimated by using the concept of black-body radiation (Norton, 1994). Outside the Solar System, the temperature approaches absolute zero. At the Earth's distance from the Sun, a tumbling meteorite has a temperature of about 277° kelvin, or 4°C, as a result of solar heating. A non-tumbling body, in contrast, would have a temperature of about 120°C on the illuminated side and –180°C on the dark side. (Of course, closer to the Sun the temperature would be much higher.) Consider the elliptical orbit of the asteroid Icarus: the temperature could be 365°C when Icarus is closest to the Sun; at the other extreme position it could be –75°C. Those values suggest that meteorites falling to Earth have a low temperature inside, and would be still quite cold to the touch even after the thermal effects of surface fusion had equilibrated.

The surface temperature of a meteorite in flight through the Earth's atmosphere depends on its size, shape, velocity, and length of time in flight. Outside the atmosphere the meteorite is cold, but while passing through the atmosphere it becomes a fireball with its surface temperature above melting. It has been suggested that 1.5 mm of diameter is lost to melting for each second in flight through the main part of the atmosphere. As a result, small meteorites burn up entirely in the atmosphere; large and dense specimens are less affected, but still lose mass through ablation.

Meteorite Craters and Effects on Life

The occurrence of craters and meteorites on planets and their satellites leads to interesting theories. Some craters are volcanic in origin, but most are thought to have been formed by impact of large meteorites. During a planet's early history, more impacts occur because impacting masses are more abundant then than later; thus the density of craters can be used to estimate a planet's age.

Craters result from an event perhaps unique to the Solar System, as are also the numerous meteorites in our collections. They resulted directly from the collision of large planetary masses that formed the asteroid belt. And thus, in this model, craters and meteorites should not be expected on planets of other solar systems in our galaxy or elsewhere in the Universe—not in the profusion we find here, because other systems probably lack the asteroid-producing event of a major planetary collision.

Life as it has evolved on our planet has been influenced—sometimes selected—by environmental effects of large meteorites. Such a history seems impossible in solar systems with no asteroids. Think about what our world would be like, and how life would have evolved, without asteroids. Some 65 million years ago, a large meteorite impacted Earth off the Yucatan Peninsula and formed the Chicxulub impact basin. That was at the end of the Cretaceous Period; it brought about extinction of the dinosaurs and also of perhaps three fourths of all species then living on Earth. If the event had not occurred, dinosaurs might have remained Earth's dominant large creatures.

Large meteorite impacts have probably affected life at other times in the geologic past, and induced other major changes in Earth's climate and magnetic features. Catastrophic events are now, more than ever, recognized as of major importance in shaping Earth history and directly changing many things. Water is the source of life, we're told—but have you hugged your meteorite lately?

Information from Meteorites

Knowledge about meteorites is important not only because of their effect on the Earth but also because of what they can tell us about the Solar System. As essentially 100% of meteorites originated in the Solar System, they provide data for modeling the temporal history and chemical formation of the planets and their moons and other bodies. Some meteorites found on our planet are believed to have come from the Moon and even from Mars; Gibson (1997) discusses evidence for microfossils in a Martian meteorite. Meteorites are the only direct source of data about the composition of the deep interior of the Earth. From meteorites we obtain data on the existence, composition, and formation of hydrocarbons in the Solar System, enabling reasonable inferences about the existence of life elsewhere, or at other times, on other planets.

To sum up this section: meteorites are a direct source of information about the physical and chemical processes that formed part of the Solar System, and about the age and timing sequence of processes that evolved the planets as they are today. Meteorites and comets are a source of materials for the planets and their moons, and comets may have provided much of the water on Earth. It is possible that they were the carriers of primitive life to Earth, and thus may have been instrumental in its beginnings here. Maybe life originated on Mars and was transported to Earth by a meteorite freed from Mars by an impacting asteroid.

RECOGNITION OF METEORITES

Description

As you might expect, meteorites come in all sizes and shapes, and many look like ordinary rocks in your pile of discards (Fig. 1). Pieces of old smelter slag are sometimes confused with meteorites because of a false idea that meteorites ought to be glassy; generally they are not, although the surface may be glassy on those with a preserved fusion crust (Fig. 2). Smelter slag usually is glassy throughout, and occurs sometimes as isolated strange dark rocks on the ground. Many meteorites look as if they had been in a fire and maybe molten on the surface (Fig. 3). Preservation of a fusion crust on meteorites depends on the nature of their impact and subsequent weathering and erosion. Falls are frequently recovered shortly after arrival, and therefore retain much of their original surface. Finds, on the other hand, probably have been exposed to the elements for a long time and thus have lost much of their original surface. Other than old smelter slag, large pieces of magnetite or hematite—usually as concretions—are the rock type most commonly mistaken for a meteorite. These materials are massive, and are rather uniformly red to reddish brown or black throughout; they also lack a fusion crust.

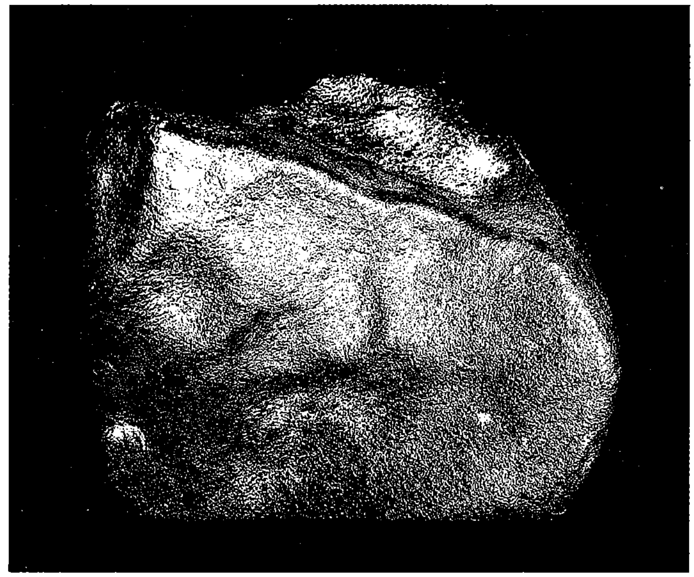

Figure 1. From Plainview, Texas; this olivine-bronzite chondrite, H5, shows fusion crust over most of its surface, which is dark brown. Specimen is 8 × 9 cm.

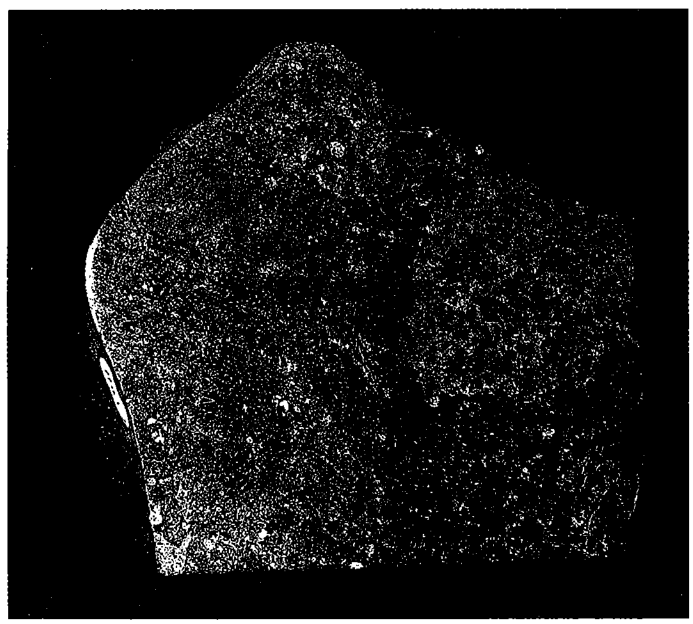

Figure 2. Plainview, Texas; this is the same specimen as in Figure 1, but here the polished surface shows fragments of a breccia structure. Specimen is 8 × 9 cm.

Color

The color of meteorite surfaces is fairly consistent, ranging through various shades of black and gray, dark brown, reddish brown, and tan. The interior of stones, beneath any fusion crust, can be light to dark gray, nearly white, brown, and almost black. Some specimens are speckled with light to dark fragments; others are brecciated (Fig. 2). The irons are metallic on the inside (Fig. 4), and reddish brown, dark brown, or black on the outside (Figs. 5–7).

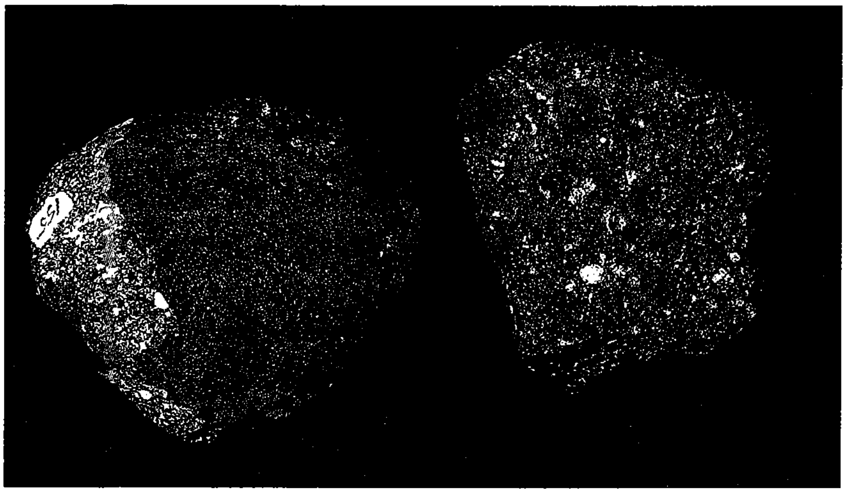

Figure 3. Allende, Mexico; here are two pieces of Allende, a carbonaceous chondrites, CV3D; one with black fusion crust over part of a light gray matrix; the second has small round chondrules set in the matrix. The rectangular fragments are 5 cm across.

Size

Meteorites also vary greatly in size. The largest known has been estimated at 60 tons in weight, and measures about 3 meters by 3 meters across and 1 meter thick. This meteorite, found in Namibia, Africa, is the Hoba meteorite. (Meteorites are usually named after a nearby community or geographic feature.)

Sizes range from the Hoba down to particles less than a millimeter in diameter. The term micrometeorite has been used to designate this fine material that has come from space and is essentially unmodified in passing through the Earth's atmosphere. Such material may be cosmic dust from space or micro-size meteorites. The Earth also receives fine material ablated from the surface of meteorites or comets that pass through its atmosphere.

Between the two extremes—the very large Hoba, and the very small micrometeorites—lie most specimens. The typical range is from a few millimeters to a few tens of centimeters in diameter, and from a few grams or tens of grams to less than 100 kilograms in weight. Small pieces, although abundant, are not often reported because recognition was difficult or the preservation poor. However, smaller fragments have been found at the site of observed falls, or in strewn fields. At these places are found fragments as small as a few grams in weight and a few millimeters or centimeters in diameter. At geologically recent explosion craters such as Arizona Crater, many small metal spheres have been found. The spheres were formed during impact and subsequent explosion, by melting and later cooling of metal from the original meteorite.

Shape and Weathering

Each meteorite has a shape almost all its own, but in general a specimen is somewhat equidimensional to flattish and rounded. Abrasion in space, or melting in the Earth's atmosphere, modifies the shape of broken pieces. A stone may undergo considerable size reduction from weathering and erosion if not recovered till long after impact. An iron, if buried, is generally covered by a weathered oxide or "iron shale" shell several centimeters or tens of centimeters thick. Thickness of the covering depends upon the original size, composition, length of time of burial, and local environment. For many irons, all that is recovered is the original meteorite's core. The shape of some irons is due to impact and explosion, modified by alteration and erosion (Figs. 6, 7).

Changes Due to Atmospheric Flight

Most meteorites have undergone surface heating during flight though the Earth's atmosphere. The heating produces local melting, with loss of liquid and considerable reduction of size. For the short time (a matter of a few seconds) that the meteorite undergoes heating and ablation, its center and the near-surface region remain cold. The depth of thermal penetration into the meteorite depends on the composition, structure, and length of time in the atmosphere; it generally approaches a centimeter. The fusion crust on stones is usually less than a millimeter thick, and locally it is shiny and brown to black. It consists of molten silicate material derived from melting of the host. Small depressions in the fusion surface are aligned along flowage directions. Any fusion surface and crust on irons resembles that on stones; it consists of a complex solidified mixture of molten metal and metal oxides, the solidified metal being nearest the host. The rear side of meteorites not tumbled during passage through the atmosphere may retain a pre-atmosphere fractured surface. For some untumbled meteorites, ablation produces a cone shape

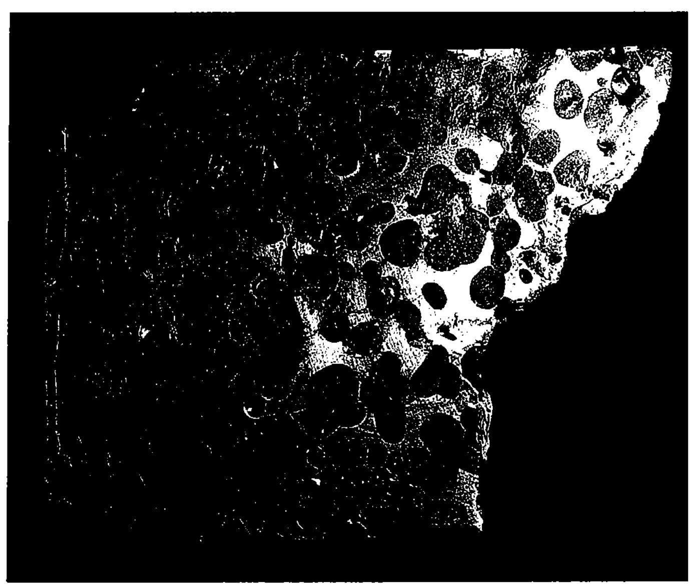

Figure 4. Brenham, Kansas; pallasite, PAL. Here crystals of olivine are set in a matrix of continuous iron-nickel alloy. Specimen is 8 × 10 cm.

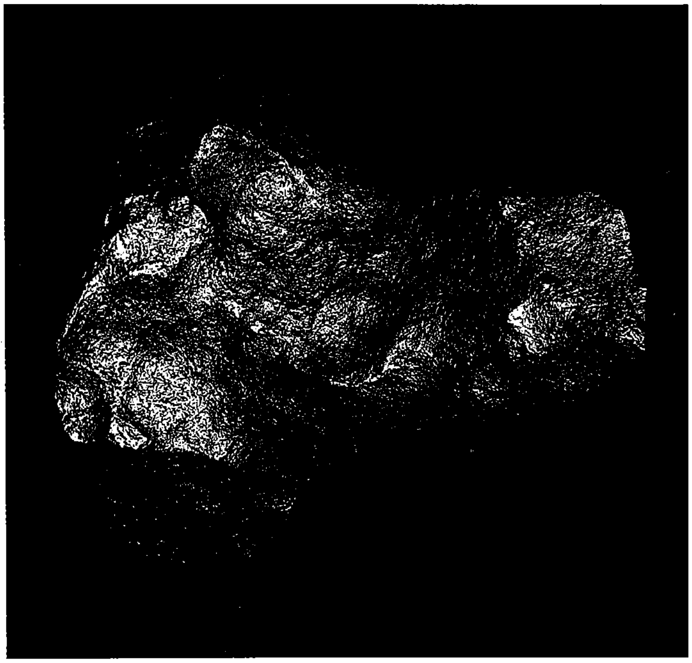

Figure 5. Gibeon, Namibia; a fine octahedrite, Of, IVA. This specimen is gray and weighs 7 lb. It shows a typical external form of octahedrites, 7.9% nickel. Specimen is 12 × 13 cm.

at the forward end, and also a surface fusion crust with elongate, rounded depressions sculptured parallel to the direction of gas flow.

The surface of many irons is marked by thumb-like depressions called regmaglypts (Fig. 6). Their size ranges from 1 centimeter to several centimeters across, with about the same depth. Regmalypts are produced by swirling gas ablation during flight through the atmosphere. As their occurrence is not limited to meteorites with large crystals of low-melting minerals (troilite, for example), they generally do not result from a melting out of former crystals as suggested by some authors. Their rounded form and even distribution also supports their origin by gas ablation. Some specimens do contain isolated angular sites where low-melting minerals probably have been removed; these pockets retain the original crystal shape. Surface erosion caused by weathering in place develops on some irons a similar sculptured surface (Fig. 7), but it is not quite the same. This erosional surface could be an enhancement, or copying, of a surface originally developed by gas ablation. As the specimen is usually surrounded by a large zone of weathered meteorite, the origin of its surface through weathering is clear. Regaglypts seem to have formed on most iron meteorites by ablation, where velocities were high and the specimen was not tumbled. Slow tumbling would produce a rounded form, with a fusion surface containing fine, smoothed, elongate flowage lines. Flight trajectory affects development of regmaglypts, for passage through the denser part of the atmosphere favors their formation.

Impact Effects and Meteorites

Impact and crater development considerably influence the shape of subsequently formed meteorite fragments. Craters like Arizona Crater, or Odessa Crater in Texas, were formed by meteorite impact and explosion. Their meteorites are of three types: (1) those produced by an explosion and a tearing apart of the iron-nickel parent upon impact; (2) those coming in flight along with the main mass, but retaining a surface formed by gas ablation and not being affected by the explosion (Fig. 6); and (3) those formed from the cooling of an iron-nickel liquid produced during the explosion. Shock effects are noted in the external shape and internal structure of the meteorites associated with the explosion. Many are clearly irregular fragments resulting from being torn apart with various angular projections, like shrapnel from bombs or artillery shells. Internally the crystals are bent, broken, or sheared by stress.

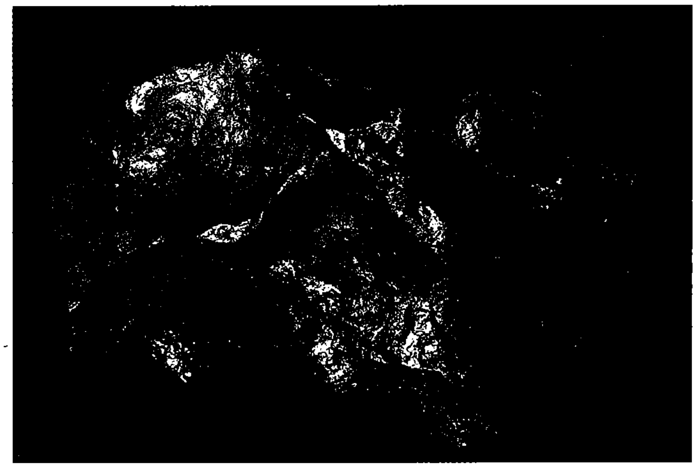

Figure 6. Canyon Diablo, Arizona; coarse octahedrite, Og, IA. This specimen is reddish brown and has well-developed, rounded depressions—regmaglypts. Specimen is 7 × 10 cm.

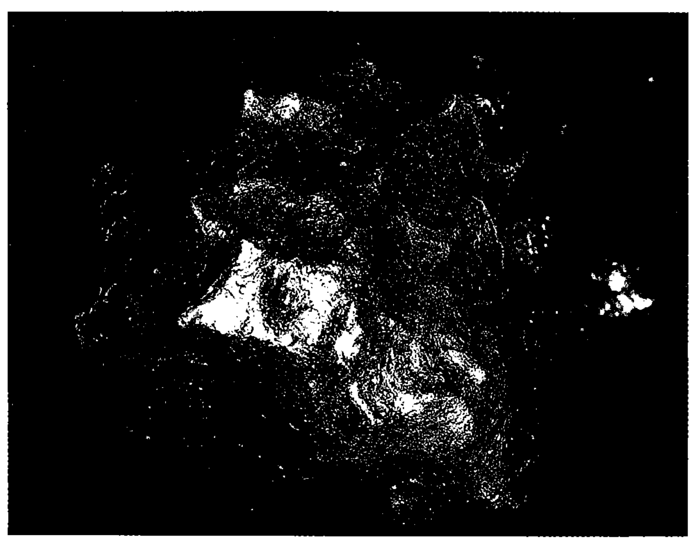

Figure 7. Henbury, Australia; this medium octahedrite, Om, IIIA, is reddish brown, and its surface shows effects of weathering in place. The specimen, which is 9 × 12 cm, was surrounded in the ground by 10 cm of oxidized iron material.

CLASSIFICATION OF METEORITES

Early Classification

Meteorites must have fascinated the earliest human observers, especially after recognition of their origin as "falling stars." With the accumulation of collections came the need to organize specimens. The earliest classification was devised by Klaproth in 1807 (Mason, 1962), who simply separated them into two groups. His elementary classification was based on composition, with those composed dominantly of silicates (stones) in one group and those made up primarily of iron minerals (irons) in the other. This grouping was soon found lacking, as observers learned more about meteorites and sought to use their new knowledge.

In one modern classification (Mason, 1962), the two-fold grouping of meteorites was retained, but each division had been broken into subgroups. The transition group called the stony-irons had been introduced by Maskelyne in 1836; they consist of about equal amounts of iron and silicate minerals. The classification used nowadays was proposed by Prior in 1920; it retains the three main divisions, but separates them into various subgroups. Prior's classification, with modifications based on increased knowledge of the structure and composition of meteorites, is outlined here.

TABLE 2. — GENERAL CLASSIFICATION OF METEORITES

Group	Subgroup*	Mineral composition
Chondrite (stony)	Enstatite (E)	Enstatite
	Olivine-bronzite (H)	Olivine, bronzite, nickel-iron
	Olivine-hypersthene (L)	Olivine, hypersthene
	Olivine-pigeonite (LL)	Olivine, pigeonite
	Carbonaceous (C3, C4)	Serpentine, organics
	Carbonaceous (C1, C2)	Serpentine, organics, water
Achondrite (stony)	Aubrite (Au)	Enstatite
	Diogenite (Di)	Hypersthene
	Ureilite (U)	Olivine, pigeonite, nickel-iron
	Howardite (Ho)	Hypersthene, plagioclase
	Eucrite (Eu)	Pigeonite, plagioclase
Stony-iron	Pallasite (P)	Olivine, nickel-iron
	Mesosiderite (M)	Pyroxene, plagioclase, nickel-iron
Iron	Hexahedrite (IIA)	Nickel-iron, 5–6% nickel
	Octahedrite (IIB, IIIA to E & IVA)	Nickel-iron, 6–14% nickel
	Ataxite (IVB)	Nickel-iron, >12% nickel

*Symbols in parentheses indicate composition and structure.

Classification and the Chondrites and Achondrites

The stones (or stony meteorites) are subdivided into two broad groups, the chondrites and the achondrites. The chondrites, as a group, are characterized by millimeter-size, round to semi-round spherules of silicate minerals called chondrules (Fig. 3); they are set in a fine-grained matrix, light to dark gray and brown. Free nickel-iron grains are particularly common in olivine-bronzite chondrites (Figs. 1, 2), and their abundance decreases in the other members of this group. The chondrites are subdivided into five subgroups, based on their mineral composition as listed in Table 2. The achondrites are more rock-like in appearance, like terrestrial basalts, diabases, peridotites, dunites, and pyroxenites, and lack the small chondrules that are abundant in chondrites. The achondrites contain only minor amounts of free nickel-iron. This group is further broken into two subdivisions, based on chemical composition: calcium-poor and calcium-rich. Each type is further divided according to mineral composition.

The Stony-Irons

The next broad group in the classification of meteorites is that of the stony-irons (Fig. 4), characterized by nearly equal amounts of silicates and nickel-iron crystals. The group is divided according to the structure and mineral composition of the silicate phase into four subgroups. Table 2 shows the two main groups of stony-irons; the other groups, being represented by only one or two specimens each, are not shown. Although the mineral composition is different in the pallasites and mesosiderites, their structure is also distinctive. The pallasites (Fig. 4) have crystallized olivine set in a matrix of continuous nickel-iron alloy crystals that have about 7–10% nickel and sometimes a Widmanstatten pattern (Fig. 8; for description see next page). Mesosiderites consist of a brecciated mass of iron and silicate minerals, apparently formed on impact by breakup and mixing of existing material. The iron alloy occurs as discrete crystals, contrasting with that in the pallasites. In some specimens of this group, shock waves during impact form tridymite, a high-temperature form of quartz.

The Irons

The last major group of meteorites is that of the irons, which are characterized by a composition of mainly nickel-iron alloys but with minor inclusions of other iron sulfide, iron silicate, and carbon minerals. The iron group is subdivided into three main divisions, based on the nickel content of the metal phase.

Use of Letter and Number Designations

Table 2 provides the detailed groupings in a classification of meteorites. This system of classification uses both composition and structure of meteorites as a basis for subdivision; no genetic implications are used or implied. In applying this classification to a particular meteorite specimen, the name of the group and subgroup are combined. As an example, a stony meteorite composed of chondrules of olivine and bronzite, with some nickel-iron crystals set in a fine-grained, dark gray matrix, would be called an olivine-bronzite chondrite. The symbol H designates this particular group. (Symbols designating other groups of stones and stony-irons are listed in Table 2.) A number is sometimes attached to the letter to

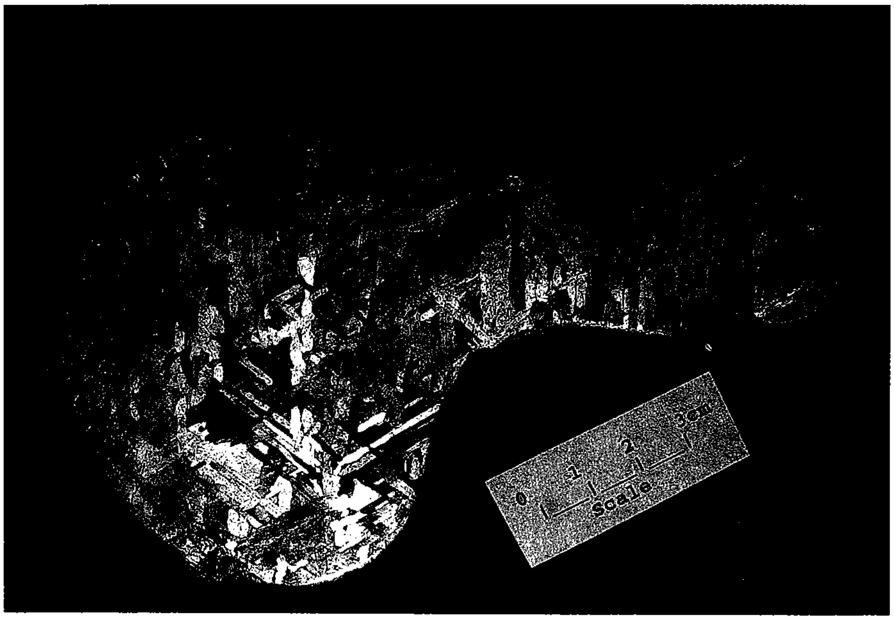

Figure 8. Toluca, Mexico; this coarse octahedrite, Og, IA, is shown as a polished and etched slab with a well-developed Widmanstatten pattern.

designate the degree of crystallization or recrystallization; for example, H5 (Fig. 2). In the iron group of meteorites: the letter H designates the hexahedrites, which have a nickel content of 5–6%; O is used for the octahedrites, nickel content 6–14% (Figs. 5–8); and D for the ataxites, nickel content >12% and no Widmanstatten pattern. The octahedrites consist of large crystals of the nickel-iron alloy mineral kamacite (alpha-iron), separated by thin lamellae of another nickel-iron alloy mineral taenite (gamma-iron). These minerals crystallize along octahedral planes of the host crystal, thus the name (Fig. 8). The angular interstices between the crystals are filled with plessite, an intergrowth of kamacite and taenite. The name Widmanstatten structure is given to the octahedral crystallization pattern of crossing bands of kamacite and taenite.

Subdivision of the Octahedrites

The octahedrite subgroup has been classically subdivided by structure into five divisions, based on the average width of the lamellae of the kamacite. "Coarsest octahedrite," symbol Ogg, is used for iron meteorites with crystal lamellae of kamacite more than 3.3 millimeters wide. "Coarse octahedrite," symbol Og, describes those with band widths of 1.3 to 3.3 millimeters; medium octahedrite, symbol Om, for those having lamellae 0.5 to 1.3 millimeters wide; fine octahedrite, symbol Of, for those having lamellae between 0.2 and 0.5 millimeters; and finest octahedrite, symbol Off, for those with lamellae <0.2 millimeters wide. Whereas the symbols Ogg to Off designate structural features of particular octahedrite groups in this classification, they are not chemically bound. The symbols given in Table 2 as II to IV with letter subdivisions represent chemical classification of the octahedrites based on content of nickel (Ni), gallium (Ga), germanium (Ge), and iridium (Ir), as suggested by Wasson and Kimberlin (1967).

Studies of the distribution of chemical elements in the structural types of iron meteorites reveal a general relationship between structural and chemical classifications. Such work also suggests that some of the chemically defined groups are genetically related, whereas others are not. Whether the various groups can each represent different environments remains to be determined. The size of original planet, as well as the depth of the source of the meteorite as to core, mantle, or crust, also needs study. The initial temperature and rate of cooling, the introduction or loss of material or fluids, and the rates of diffusion all need research. Many of those factors would have influenced formation of meteorites.

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new OGS publications

CIRCULAR 105

- Kenneth S. Johnson, *editor*
- 179 pages
- Paperbound, laminated cover
- $11

Silurian, Devonian, and Mississippian Geology and Petroleum in the Southern Midcontinent, 1999 Symposium

Contained in this volume are papers dealing with the search for, and production of, oil and gas resources from reservoirs of Silurian, Devonian, and Mississippian age in the southern Midcontinent. The research focuses on the reservoirs, geologic events, and petroleum of rocks deposited during the Silurian, Devonian, and Mississippian Periods. Clastic and carbonate reservoirs of this age are major sources of oil and gas in the southern Midcontinent, and they have great potential for additional recovery using advanced technologies.

The 26 papers and abstracts in this book concentrate on geology, depositional settings, diagenetic history, reservoir characterization, sequence stratigraphy, exploration, petroleum production, coalbed methane, and enhanced oil recovery. The research originally was presented at a two-day workshop held in March 1999 in Norman, Oklahoma, cosponsored by the OGS and the National Petroleum Technology Office of the U.S. Department of Energy. The meeting drew about 200 representatives from industry, government, and academia. In describing these petroleum reservoirs of Silurian, Devonian, and Mississippian age, the researchers involved in this meeting increased our understanding of how the geologic history of an area can affect reservoir heterogeneity and the ability to efficiently recover hydrocarbons.

Among the reservoirs discussed are: Hunton, Misener, Woodford, Springer, Chester, and other Silurian, Devonian, and Mississippian units. Study areas include many major fields in Oklahoma, as well as sites in Kansas, Colorado, Texas, and New Mexico. As oil prices have increased recently, a greater interest in drilling in the State makes these papers a valuable resource for explorationists and operators in Oklahoma.

EDUCATIONAL PUBLICATION 7

- *by* James R. Chaplin
- 82 pages
- Three-ring binder
- $12

Reading Topographic Maps—Activities for Earth Science Teachers and Students

This publication shows how to read topographic maps and use them in everyday life by outlining the principles of maps and mapping, with guides to resources for further study. Primarily intended as a resource for teachers, the book also is useful for students and anyone else interested in facts about the earth and how we find our way around it.

A variety of activities (including crossword puzzles, word searches, and geodetectives) teach students about map colors and symbols, map language, and how to read and draw contours. The activities generally are intended for grades 6–12. Some of the activities are tailored to a particular area (among them are the Ada, Bethany NE, Oologah, and Turner Falls quadrangles), but the information can be adapted to other geographic areas and topographic maps. The publication also includes the U.S. Geological Survey booklets *Topographic Map Symbols* and *Oklahoma—Index to Topographic and Other Map Coverage.*

Circular 105 and **Educational Publication 7** can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. To mail order, add 20% to the cost for postage, with a minimum of $2 per order.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office, 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886, fax 405-366-2882, e-mail ogssales@ou.edu. Request the OGS *List of Available Publications* for current listings and prices.

OGS hosts field trip to the Garber aquifer

Saturday, March 30, 8 a.m. to 4 p.m.

• Trip is free • Non-technical • For the public • Students and educators welcome

The Oklahoma Geological Survey is sponsoring a free field trip for the public to key geological sites near Norman. Geoscientists and engineers from several local, state, and federal agencies will explain where much of Norman's ground water comes from, discuss Norman's water wells, and describe on-going work being done in Norman by the Oklahoma and U.S. Geological Surveys. They will lead discussions and answer questions throughout the day.

Logistics

The trip will proceed by caravan to the various geologic sites. Participants will drive their own cars, or carpool with others, and they must provide their own lunches, drinks, and lawn chairs.

There are no scheduled bathroom stops on the trip; however, maps of the field-trip route will be handed out, and participants can catch up with the trip at any time.

Preliminary Itinerary and Discussion Topics

Participants will meet at Alameda Street entrance to Lake Thunderbird State Park (Indian Point Information Center) at 8:00 a.m., Saturday, March 30.

• ***Stop 1*** • Walking distance of Indian Point Information Center. Neil Suneson (geologist, OGS) will talk about the geology of this part of Oklahoma, the Garber Sandstone formation, and what geologists think Oklahoma looked like when the Garber Sandstone was deposited. John Harrington (geohydrologist and director, Garber-Wellington Association/Association of Central Oklahoma Governments) will explain what an aquifer is and why the Garber Sandstone is such a good aquifer. We also will discuss the concept of recharge area and compare it to what we will see at the last stop of the day.

• ***Stop 2*** • Alameda Street, near Lake Thunderbird. The topic is the official State Rock of Oklahoma—the rose rock, or barite rose. David London (professor, OU School of Geology and Geophysics) will discuss the origin of rose rocks and why they occur in the Garber Sandstone. Field trip participants will have the opportunity to observe rose rocks as they occur in the outcrop and collect some rose rocks of their own.

• ***Stop 3*** • Norman Water Well No. 40, ½ mile east of 36th St. NE and Tecumseh. Several engineers with the Norman Utilities Department will explain how the City drills and completes water wells. Bruce Myers will set up a water-well drilling rig and describe the drilling operations. Bryan Hapke and Vernon Campbell will explain how Norman's water wells are constructed and how the City operates its well field.

• ***Stop 4*** • Oklahoma Geological Survey Core and Sample Library and lunch, 2725 S. Jenkins. If the weather is pleasant, we will set up lawn chairs outside and have lunch (brown-bag, participants are responsible for their own lunches). If the weather is inclement, arrangements will be made to have lunch inside the facility. Walt Esry (OGS) will lead brief tours of the facility, and Neil Suneson will describe cores of the Garber Sandstone and Hennessey Shale.

• ***Stop 5*** • Old Norman landfill and U.S. Geological Survey research site. Scott Christenson (hydrologist) and Jamie Schlottmann-Norvell (geochemist), USGS Water Resources Division in Oklahoma City, will discuss their work on contamination of the Canadian River alluvium from the former Norman landfill. They also will discuss landfills in general, ground-water contamination by humans, and the natural dilution of contamination.

• ***Stop 6*** • Hennessey Shale outcrop on east side of 48th St. NW, just south of Franklin Road. Borrow pit is owned by Bruce Payne. Participants will examine the Hennessey Shale (the formation that overlies the Garber Sandstone aquifer) and discuss what geological conditions caused the shale to be deposited over the sandstone and how the Hennessey forms a "cap" on the aquifer. We will discuss the difference between a confined and unconfined aquifer and compare it to the recharge area (see Stop 2). The origin of arsenic and other trace elements in some of Norman's ground water also will be discussed at this stop. Neil Suneson will explain the geology and Jamie Schlottmann-Norvell will discuss the water geochemistry.

Registration

Registration is limited to the first 80 who apply. Participants can register for the field trip one of two ways:

OGS Web site: http://www.ou.edu/special/ogs-pttc/
or Phone (405) 325-3031

OGS Workshop

FINDING AND PRODUCING CHEROKEE RESERVOIRS IN THE SOUTHERN MIDCONTINENT

Oklahoma City, Oklahoma, May 14–15, 2002

A two-day program co-sponsored by the OGS and the National Petroleum Technology Office of the U.S. Department of Energy will examine techniques, technology, and new ideas that provide practical aids to understanding the nature of Cherokee-age hydrocarbon reservoirs. An effort to review pitfalls and failed techniques, as well as those that succeed, will be one of the workshop's main goals.

Sandstones of the Cherokee and its equivalents are among the most prolific petroleum reservoirs in Oklahoma, responsible for approximately 15% of the gas and more than 50% of the oil that has been found thus far. The Cherokee also is one of the most wide-ranging producing intervals in the southern Midcontinent and continues to rank as one of our most important exploration targets.

This is the 15th workshop in an annual series designed to aid in the search for, and production of, our oil and gas resources. It will be held at the Meridian Convention Center in Oklahoma City. In addition to the oral papers listed below, there will be approximately 15 poster sessions and 10 commercial exhibits.

- **The Red Fork Sandstone: An Overview of Fluvio-Deltaic Platform and Shelf Reservoirs**, by Zuhair Al-Shaieb and Jim Puckette, *Oklahoma State University*
- **A Petrophysical Study of the Prue Formation in Washita County, Oklahoma: A Multiple Parameter Approach to Log Analysis**, by George A. Anderson III, *Texas Tech University*
- **Red Fork Production in the Cherokita and Wakita Trends in Grant and Alfalfa Counties, North-Central Oklahoma: Is the Reservoir a Fluvial Incised Channel or Marine Shoreline System, and Who Cares?**, by Richard D. Andrews, *Oklahoma Geological Survey*
- **Preliminary Conodont Biostratigraphy of the Lower Desmoinesian Cherokee Group of Oklahoma and Southern Kansas**, by Darwin R. Boardman II and Tom R. Marshall, *Oklahoma State University*
- **A Deposition and Reservoir Model for the Prue Sandstone in the Southwest Oklahoma City Area**, by John R. Broker, *Helmerich And Payne Inc.*; Les J. Broker, *Consultant*; and Thomas N. Capucille, *Consultant*
- **Development of Transition Zone Reserves Around Abandoned Production: A Case Study of Mount Vernon Field, Lincoln County, Oklahoma**, by David Chernicky and Scott T. Schad, *Chernico Exploration*
- **Dipmeter Navigation of the Location and Orientation of a Cherokee Sandstone Reservoir: A Kansas Case Study**, by John H. Doveton, *Kansas Geological Survey*
- **Accurate Geological Model for Enhanced Oil Recovery in a Fluvial Bartlesville Channel Sand in Delaware-Childers Field, Nowata County, Oklahoma**, by Mohamed A. Eissa, John P. Castagna, and Roy M. Knapp, *University of Oklahoma*
- **Red Fork Sandstone of Oklahoma: Depositional History, Sequence Stratigraphy and Reservoir Distribution**, by Richard D. Fritz, *American Association of Petroleum Geologists*; and Edward A. Beaumont, *Consultant*
- **Cherokee Equivalent Formations of the Ardmore Basin: A New Look at Old Data**, by Robert E. Harmon, *C. E. Harmon Oil, Inc.*
- **Bluejacket to Bartlesville, Surface to Subsurface**, by G. Carlyle Hinshaw, *Consultant*
- **Facies Architecture of the Skinner and Bartlesville Sandstones, Southwestern Rogers County, Oklahoma**, by Dennis R. Kerr and Alexander A. Aviantara, *University of Tulsa*
- **Middle Desmoinesian Subsurface Sequence Stratigraphy, Creek and Okfuskee Counties and Adjacent Areas, Oklahoma**, by Dennis R. Kerr, Yosi Hirosiadi, and Dwi K. Hustiara, *University of Tulsa*
- **Outcrop-Based Cyclic Stratigraphy of the Cherokee Group**, by Tom R. Marshall and Darwin R. Boardman II, *Oklahoma State University*
- **The Red Fork Sandstone: An Overview of Marine and Deep-Marine Reservoirs**, by Jim Puckette and Zuhair Al-Shaieb, *Oklahoma State University*
- **Cherokee Paleolithology, Long Branch Field, Payne County, Oklahoma**, by Greg A. Riepl, *Independent Geologist*
- **The East Clinton Gas Field—A Seismic-Stratigraphic Case Study**, by Richard E. Schneider, *Schneider Strata Science Inc.*
- **Opportunity Identification Using Integrated Modeling Techniques: Cherokee-Age Hydrocarbon Reservoirs**, by Bob Shelley and Bill Grieser, *Halliburton Energy Services*
- **Gas in an Incised Valley, Upper Cherokee Age, Eastern Kansas**, by William T. Stoeckinger, *Geological Consultant*

REGISTRATION INFORMATION

The fee for advance registration (*by May 6*) is $60 and includes lunches and a copy of the proceedings; late and on-site registration is $70. Students rates are available.

For more information, contact Dan Boyd (email: dtboyd@ou.edu), Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 or (800) 330-3996. For registration forms, contact Tammie Creel (tcreel@ou.edu) or Jan Coleman (jlcoleman@ou.edu) at the same address and phone numbers.

upcoming meetings

MARCH

American Association of Petroleum Geologists, Spring Student Expo, March 15–16, 2002, Norman, Oklahoma. Information: Sue Crites, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd, Suite 810, Norman, OK 73019; (405) 325-8971; e-mail: scrites@ou.edu. Web site: http://geology.ou.edu.

Society for Sedimentary Geology (SEPM) Research Conference, "Aquifer Heterogeneity and Environmental Implications: Ancient and Modern Coastal Plain Depositional Environments," March 24–27, 2002, Charleston, South Carolina. Information: M. K. Harris, Savannah River Technology Center, P.O. Box 616, Bldg. 773-42A, Aiken, SC 29808; (803) 725-4184; fax 803-725-7673; e-mail: mary.harris@srs.gov. Web site: http://www.sepm.org.

Oklahoma City Geological Society/Oklahoma Geological Survey/Petroleum Technology Transfer Council, Coalbed-Methane Workshop, March 27, 2002, Oklahoma City, Oklahoma. Information: OCGS, 120 N. Robinson, Suite 900 Center, Oklahoma City, OK 73102; (405) 236-8086 *or* (405) 235-3648, ext. 40; fax 405-236-8085. Web site: http://www.ocgs.org.

National Earth Science Teachers Association, Annual Meeting, March 27–30, 2002, San Diego, California. Information: NESTA, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6910; fax 202-328-0566; e-mail: fireton@kosmos.agu.org.

APRIL

American Association of Petroleum Geologists, Hedberg Research Conference, "Near-Surface Hydrocarbon Migration: Mechanisms and Seepage Rates," April 7–10, 2002, Vancouver, British Columbia. Information: Debbi Boonstra, AAPG Education Dept., P.O. Box 979, Tulsa, OK 74101; (918) 560-2630; fax 918-560-2678; e-mail: debbi@aapg.org. Web site: http://www.aapg.org/education/hedberg/vancouver.html.

Geological Society of America, South-Central Section, Annual Meeting, April 11–12, 2002, Alpine, Texas. Information: Kevin Urbanczyk, Dept. of Earth and Physical Science, Sul Ross State University, SRSU Box C-143, Alpine, TX 79832; (915) 837-8110; e-mail: kevinu@sulross.edu.

Society of Economic Geologists, Global Exploration 2002, "Integrated Methods for Discovery," April 14–16, 2002, Denver, Colorado. Information: e-mail: SEG2002@segweb.org. Web site: http://www.SEG2002.org.

MidAmerica GIS Consortium (MAGIC), April 14–18, 2002, Kansas City, Missouri. Information: Tim Haithcoat, Geographic Resources Center, University of Missouri–Columbia, 104 Stewart Hall, Columbia, MO 65211. Web site: http://magicweb.kgs.ukans.edu.

Society of Petroleum Engineers/U.S. Dept. of Energy, Symposium on Improved Oil Recovery, April 16, 2002, Tulsa, Oklahoma. Information: IOR 2002, c/o David Olsen, One W. Third St., Tulsa, OK 74103; fax 918-699-2048. Web site: http://www.npto.doe.gov/ior.

Rocky Mountain Federation of Mineralogical Societies, Regional Show, April 19–21, 2002, Enid, Oklahoma. Information: Stan Nowak, 2805 Sage Dr., Enid, OK 73701; (580) 234-1966; e-mail: snowak48@yahoo.com.

Oklahoma City Geological Society/Oklahoma Geological Survey/Petroleum Technology Transfer Council, Bartlesville Play Workshop, April 23, 2002, Oklahoma City, Oklahoma. Information: OCGS, 120 N. Robinson, Suite 900 Center, Oklahoma City, OK 73102; (405) 236-8086 *or* (405) 235-3648, ext. 40; fax 405-236-8085. Web site: http://www.ocgs.org.

Tulsa Geological Society/Oklahoma Geological Survey/Petroleum Technology Transfer Council, Bartlesville Play Workshop, April 25, 2002, Tulsa, Oklahoma. Information: TGS, 4308 S. Peoria, Tulsa, OK 74105; (918) 582-4762. Web site: http://www.tulsageology.org.

MAY

Society of Independent Earth Scientists, Annual Meeting, May 1–4, 2002, Lafayette, Louisiana. Information: SIPES, 4925 Greenville Ave., Suite 1106, Dallas, TX 75206; (214) 363-1780; fax (214) 363-8195; e-mail: sipes@sipes.org. Web site: http://www.sipes.org.

American Association of Petroleum Geologists/Society of Petroleum Engineers, Joint Technical Conference, "Energy Frontiers—A 2002 Perspective," May 18–23, 2002, Anchorage, Alaska. Information: Bob Swenson, Phillips Alaska, Inc.; (907) 265-6808; e-mail: rswenson@ppco.com. Web site: http://www.aapg-spe-2002.org.

JUNE

OU School of Petroleum and Geological Engineering/Oklahoma Geological Survey, Conference on Naturally Fractured Reservoirs, June 3–4, 2002, Oklahoma City, Oklahoma. Information: Michael L. Wiggins, University of Oklahoma, 100 E. Boyd, Suite T-301, Norman, OK 73019; (405) 325-6781; fax 405-325-7477; e-mail: mwiggins@ou.edu. Web site: http://www.ou.edu/mewbourneschool.

American Association of Petroleum Geologists, Southwest Section, Annual Meeting, June 6–8, 2002, Ruidoso, New Mexico. Information: AAPG, P.O. Box 979, Tulsa, OK 74101; (800) 364-2274 *or* (918) 560-2679; fax 800-281-2283 *or* 918-560-2684. Web site: http://www.aapg.org/meetings/.

Clay Minerals Society, Annual Meeting, June 8–13, 2002, Boulder, Colorado. Information: Kathryn Nagy, Dept. of Geological Sciences, University of Colorado, Boulder, CO 80309; (303) 492-6187; fax 303-492-2602; e-mail: kathryn.nagy@colorado.edutel. Web site: http://www.colorado.edu/geolsci/cms/.

Interstate Oil and Gas Compact Commission, Midyear Meeting, June 9–11, 2002, Traverse City, Michigan. Information: IOGCC, P.O. Box 53127, Oklahoma City, OK 73152; (405) 525-3556; fax 405-525-3592; e-mail: iogcc@iogcc.state.ok.us. Web site: http://www.iogcc.state.ok.us/.

Oklahoma Commission on Marginally Producing Oil and Gas Wells, Trade Fair, June 14, 2002, Tulsa, Oklahoma. Information: Sam Farris, 1218-B W. Rock Creek Road, Norman, OK 73069; (405) 366-8688; e-mail: sfarris@mhs.oklaosf.state.ok.us.

Oklahoma Geological Survey/Petroleum Technology Transfer Council Workshop, "Practical Reservoir Characterization for the Independent Operator," June 24–25, 2002, Norman, Oklahoma. Information: Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069; e-mail: tcreel@ou.edu. Web site: http://www.ou.edu/special/ogs-pttc/.

Upcoming Workshop and Field Trips for Earth-Science Educators

– Workshop and Field Trip –

Sponsored by U.S. Department of Energy, National Petroleum Technology Office

Petroleum Earth-Science Resources for the Classroom
Tuesday, April 16, 2002, Tulsa

This *FREE* one-day workshop will provide middle and high school teachers with information and hands-on activities from organizations such as the Oklahoma Geological Survey, U.S. Geological Survey, and Society for Exploration Geohysicists. Topics will include:

Coring—Clues for Finding Oil and Gas. Core samples will be examined to demonstrate geological concepts, determine rock types, construct a graphic log, and correlate core samples from different wells.

The Fossil Record—Reconstructing the Earth's History. Hands-on activities will include "Chances of Becoming a Fossil in the Rock Record," "Classifying Fossils," "Reconstructing the Stratigraphic Record Using Fossils," and "Fossil Correlation of Rock Layers." Fossil specimens for classroom use will be provided.

Applications of Geology and Geophysics. A number of earth-science activities will be presented including mineral identification, rock porosity measurements, contour map construction, and a plate tectonics activity puzzle. Earth-science kits and a video on earth-science careers will be provided.

Information and Activities Available from the USGS. The USGS is the nation's largest water, earth, and biological science and civilian mapping agency. It employs specialists on plants and animals, rocks, mineral resources, water, geography, natural hazards, map-making, earth imaging, and hosts of other natural sciences to gather data, integrate it, and demonstrate its application to today's issues. Information and classroom activities available from the USGS will be demonstrated and provided.

Famous Oklahoma Shoestring Sandstone Oil Reservoirs
Sunday, April 14, 2002, departing from Tulsa

Oil was producing during the Oklahoma oil boom days from several shoestring sandstones that are now well exposed in northeastern Oklahoma road cuts. This field trip will visit three of the sandstones: the Nellie Bly, the Gypsy, and the Bartlesville. Each of these has been the subject of considerable research that will be explained while viewing the outcrops. There also will be a fossil collecting stop at Skiatook Dam and a visit to the drilling test facilities at the Port of Catoosa. A stop will be made to sample a black shale oil source rock at a limestone quarry. This field trip is recommended for petroleum engineers, geologists, and earth-science teachers at any level.

Buses depart from the Tulsa Marriott Southern Hills hotel lobby at 8:30 a.m. (please arrive by 8:00 a.m.) and return to the hotel lobby at 5:00 p.m. A BBQ lunch will be provided.

Field trip cost: $35. Teachers from middle or high schools may attend *FREE.*

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Workshop and field trip registration: Susan Jackson, DOE–National Petroleum Technology Office, One West Third St., Suite 1400, Tulsa OK 74103; phone (918) 699-2018; fax 918-699-2060; e-mail: susan.jackson@npto.doe.gov.
Web site: http://www.npto.doe.gov/ior/FieldTrip.html

– Field Trips –

Sponsored by Oklahoma City Geological Society

Geologists from the Oklahoma City Geological Society and the Oklahoma Geological Survey will lead the following field trips designed for earth-science teachers. The stratigraphy and structure of the exposed rocks and their relationship to current landforms and geologic history will be explained, as well as their environmental and economic impact. Field trip participants may collect rock samples and fossils for classroom use.

Cost: $25. Guidebook, transportation, soft drinks, coffee, and donuts provided; bring your own lunch.

Wichita Mountains Geologic Field Trip
Saturday, April 6, 2002, departing from Oklahoma City

This field trip will visit locations in the eastern Wichita Mountains that illustrate common geologic principles. The emphasis is on igneous rocks and their weathering and erosion and how this is reflected in the landforms (topography) of the Wichita Mountains.

Rocks exposed in the Wichita Mountains consist mainly of what is known as "basement rocks"—generally igneous rocks (granite, rhyolite, gabbro, diabase) that typically underlie the younger sedimentary rocks that were deposited over most of Oklahoma. There are 11 stops scheduled to view rocks that include granites cut by a few diabase dikes and rhyolites (both are very fine grained granitic type rocks deposited on or near an old surface), gabbros (dark blue-gray crystalline rocks), quartzites and limestones, all of Cambrian age (500 million years old), and the Permian-age Post Oak Conglomerate (260 million years old), consisting of debris of the older rocks eroded from the basement after the Wichita Mountains formed.

The trip begins at Oklahoma City Community College and travels southwest on I-44 to rendezvous at the Loves Store on Highway 49, Exit 45, with others from south and western Oklahoma. The trip will take about 11 hours.

Arbuckle Mountains Geologic Field Trip
Saturday, April 27, 2002, departing from Moore

The emphasis of this field trip is on sedimentary rocks, their attitude, composition, weathering, and erosion and how this is reflected in the landforms (topography) of the Arbuckle Mountains. Participants will view rocks ranging in age from 570 million years old (Cambrian) to sediments currently being deposited in Honey Creek and the Washita River. The Colbert Rhyolite (525 million years old), some of the oldest rocks exposed in the Arbuckle Mountains, are visible from the Turner Falls Overlook stop. Also visible at this stop is the travertine (one of the youngest sediments) being deposited by Honey Creek as it flows over Turner Falls.

The trip begins at the Wal-Mart parking lot in Moore and travels south on I-35 to the Arbuckle Mountains where 14 stops are scheduled at various outcrops and quarries, ending in Platt National Park, Sulphur. The trip will take about 10 hours.

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Field trip registration: Carol Jones, Oklahoma City Geological Society, 120 N. Robinson, Suite 900 Center, Oklahoma City, OK 73102; (405) 235-3648; fax 405-236-8085; e-mail: ocgs@oklahoma.net.
Web site: http://www.ocgs.org.

AAPG Annual Convention
Houston, Texas
March 10-13, 2002

On behalf of the Houston Geological Society and the AAPG 2002 Coordinating Committee, I extend my sincere invitation to you to actively participate in the 2002 Annual Convention of the American Association of Petroleum Geologists, its divisions—the Division of Environmental Geosciences, the Division of Professional Affairs, the Energy Minerals Division—and the SEPM (Society for Sedimentary Geology) in Houston, Texas, March 10–13. Houston is more and more the "energy capital" of the world with offices of many U.S. and international E&P and service companies.

The theme of the meeting, "Our Heritage: Key to Global Discovery," is meant to honor and derive value from our predecessors and their vast experience. As geologists, we can use our heritage as a key to unlock new discoveries worldwide. It is the belief of the Convention Coordinating Committee that it is truly a case of the past being a key to our future!

Aligning with the theme, the convention will include sessions to address specific geologic issues such as sequence stratigraphy, biostratigraphy, depositional systems, hydrocarbon generation and migration, reservoir geology, diagenesis, and the environment. Broader-based issues such as technology, visualization, exploration techniques, worldwide E&P activity, business activity, professional development and career concerns, and the global aspects of the challenges we face will also be highlighted.

A special session called "Discoverers of the 20th Century" will examine major oil and gas fields—and the processes and events which led to their definition—with the presentations being made by invited experts who experienced and drove the discovery process. Their stories are the source of much of our heritage!

Students and young professionals will be welcomed, and special sessions addressing their needs and interests are planned. Poster sessions with interactive e-posters will also expand the opportunities for participation in the convention's technical program.

The broader aspects of the "discovery process" will be addressed with special sessions and events focusing on space exploration and the role of geologists in the great adventure.

We believe the 2002 Annual Convention will be a time to reflect on the heritage and future of the profession of petroleum geology, and we look forward to hosting this exciting event.

Jeffrey W. Lund
General Chairman

Convention Agenda

Technical Program

Sunday, March 10

History of Petroleum Geology Forum: Petroleum Geology in Selected States

Monday, March 11

Deepwater Source Rocks and the Petroleum Systems of the Atlantic Margin
Business Challenges Facing Deep-Water Development
Human Exploration of Earth, Moon, and Mars
Eustatic, Tectonic, and Sedimentary Control on Depositional Sequences: Relative Importance
Crude Oil Alteration—Processes and Examples
North American Resources: Remaining Exploration Potential Onshore
Uranium Energy: Source to Power to Repository
Stratigraphy and Controls on Development of Isolated Carbonate Platforms
Rock Physics: The Missing Link between Geology, Geophysics, and Production
Technology Trends—Keys to Profitability
E&P Activities of Northern South America and the Caribbean
Portfolio Economics and Management
Understanding Complex Traps—Focus on Stratigraphy
Beyond Amplitudes: Examples of Geophysical Techniques Leading to Successful Development of Non- to Marginal-Amplitude Plays
Geospatial Information Systems—Integration of Technologies and New Sensors
Oligocene and Miocene Carbonate Platforms
Fluvial, Estuarine, and Near-Shore Processes: Lessons from the Quaternary

Tuesday, March 12

Rock Physics: The Missing Link between Geology, Geophysics, and Production
Gas in the Marketplace—Strategies for Development
Discoverers of the 20th Century
Understanding Complex Traps—Focus on Compression
E&P Activities in North Africa and the Arabian Platform
SEPM Research Symposium: Modern Seafloor Swath and Subsurface Seismic 3-D Images: Implications for Deep-Water Systems Models and Deep-Water Plays
Changing Business Conditions in Developing Countries
Basin Scale Fluid Flow and Diagenesis
Chronostratigraphy and Sequence Stratigraphy: Pushing the Limits of Correlation and Resolution
The Petroleum Geology of Mexico—Past, Present, Future
The Future of Petroleum R&D

Understanding Complex Traps—Focus on Extension and Inversion
New Frontiers in Coal and Coalbed Methane
E&P Activities in Eastern Canada
North Sea and Beyond—Exploration and Production
Sequence Stratigraphy of Fluvial, Estuarine, and Near-Shore Deposits: The Influence of Base Level and Climate
Carbonate and Evaporite Sequence Stratigraphy: Recent Advances and Controversies
Remediation of Affected Soil and Groundwater

Wednesday, March 13

Portfolio Economics and Management
E&P Activities on the African Atlantic Margin
Geology and Hydrocarbon Potential of the Zagros Foldbelt and Foredeep
A New Look at Old Fields: Examples of Reworked Fields Yielding Significant New Reserves
Gulf of Mexico—Naturally Occurring Oil Seeps, Impact of Synthetic Muds, and Discharge of Cuttings
Salt Tectonics Exploration Issues, Gulf of Mexico
E&P Activities in the Caspian
Are Major Deltas Complete Petroleum Systems unto Themselves? Evidence and Controversies
Intraslope Compared to Ocean Basin-Floor Turbidite Systems
Selections from the Society of Petroleum Engineers: SPE 2001
DPA Forum: Improving the DPA Certification Process for International AAPG Members
"Pass the Salt, Please": Recent Advances in Global Salt Tectonics
Brazil Partnerships—Status of E&P Activities
Selections from the Society of Exploration Geophysicists and European Association of Geoscientists and Engineers: SEG and EAGE 2001
Successful Application of Non-Seismic Techniques to Exploration
Exploring the World at Large
Mesozoic Carbonate Reservoir and Outcrop Analogs: Circum Gulf of Mexico and Arabian Gulf
Biostratigraphy and Sequence Stratigraphy: Biotic and Taphonomic Response to Sea-Level Fluctations
Miocene Systems, Sequences, Cycles, and Reservoirs of the Gulf of Mexico Basin
Biogenic Gas Formation, Occurrence, and Implications

Short Courses

Pre-Convention

Modern Turbidite Systems as Analogs for Deep-Water Petroleum Plays, *March 8–9*
Oil and Gas Property Auctions: Successful Internet Applications to an Existing Business, *March 8*
Tax, Trade, and Legal Considerations, *March 8*
Surgical Theater Review of Exploration Plays, *March 9–10*
Development Geology, Reservoir Characterization, and Management, *March 9*
Rock-Based Integration: Geologic Interpretation of the Integration of Seismic and Petrophysical Data, *March 9*
Horizontal Technology for Geologists, *March 10*
Low-Resistivity, Low-Contrast Pays, *March 10*
Introduction to the Petroleum Geology of Deep-Water Clastic Depositional Systems, *March 7–9*
Geological Well Logs—Their Use in Reservoir Modeling, *March 9–10*
Deep-Water Sands, Integrated Stratigraphic Analysis—A Workshop Using Multiple Data Sets, *March 9–10*
Marine Geohazards: Acquisition and Interpretation, *March 9–10*
Preparing for National Geoscience Exams, *March 9*
Private Capital Financing: A Guide to Fame and Fortune, *March 10*
Oil and Gas Contracts, *March 10*
Coalbed Methane Exploration and Development: A Review of International and Domestic Coalbed Methane Opportunities, *March 9*
Interpretation of Clastic Depositional Environments from Core and Well Logs, *March 9–10*
Seal and Reservoir Flow Barrier Analysis and Prediction, *March 9–10*
Recent Developments in Quantitative Biostratigraphy and Paleoecology, *March 9–10*
Deep Water Core Workshop—Northern Gulf of Mexico, *March 10*
Sequence Stratigraphy for Graduate Students, *March 9–10*

Post-Convention

E&P Methods and Technologies: Selection and Applications, *March 14–16*
Pore Pressure Prediction in Practice, *March 14–15*
Understanding the Nature of Seismic Data, *March 14–15*

Field Trips

Pre-Convention

Gulf of Mexico/Ouachita Mountains Deep-Water Reservoir Analogs, *March 8–10*
Hockley Salt Mine, *March 9*
Erosion and Land Use along the Upper Texas Coast, *March 9*
Modern Deltaic Environments, *March 8–9*
South Texas Project—Nuclear Power Plant, *March 9*
Texas Low-Rank Coals—Geologic Setting and Coalbed Gas Potential, *March 10*
Coalesced-Collapsed Paleocave Systems: Origins, Spatial Complexity, and Reservoir Implications, *March 7–9*
Modern Depositional Systems of the East Texas Coast—Graduate Student Field Trip, *March 9*

Post-Convention

Mesozoic Tectono-Stratigrahic and Paleogeographic Evolution of Northeast Mexico: Outcrop Analogs for Gulf of Mexico Exploration and Production, *March 13–17*
Outcrop Examples of Permian Basin Play Types in the Hueco and Guadalupe Mountains of Texas and New Mexico: A Sequence Stratigraphic Perspective, *March 13–17*
Wineries, Geology, Frontier History of the Llano Uplift, *March 14–15*
Reservoir Architecture of the Deep-Water Brushy Canyon Formation, West Texas, *March 13–17*
Belize Shelf and Coastal Depositional Systems, *March 14–20*
Modern Depositional Systems of the East Texas Coast, *March 14–15*

For more information about the annual meeting, contact AAPG Annual Convention, P.O. Box 979, Tulsa, OK 74101; phone (800) 364-2274 *or* (918) 560-2679; fax 800-281-2283 *or* 918-560-2684. World Wide Web: www.aapg.org/meetings/houston02.

U.S. Geological Survey World Wide Web Information

USGS Fact Sheet 0033-01

The USGS World Wide Web sites offer an array of information that reflects scientific research and monitoring programs conducted in the areas of natural hazards, environmental resources, and cartography. The list in this 2-page Fact Sheet provides gateways to access a cross section of the digital information on the USGS World Wide Web sites.

Order Fact Sheet 0033-01 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone 1-888-275-8747. Fact sheets are available at no cost. This Fact Sheet also is available on the Web at http://mac.usgs.gov/isb/pubs/factsheets/fs03301.html.

Educational Materials from the U.S. Geological Survey

USGS Fact Sheet 0044-01

As the nation's largest water, earth, and biological science and civilian mapping agency, the USGS provides some of this science information as educational material. The product line includes a variety of teaching packets, booklets, posters, fact sheets, and CD-ROMs. This 8-page Fact Sheet describes products designed for K–12 teachers.

Order Fact Sheet 0044-01 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone 1-888-275-8747. Fact sheets are available at no cost. This Fact Sheet also is available on the Web at http://mac.usgs.gov/isb/pubs/factsheets/fs04401.html.

Finding Your Way With Map and Compass

USGS Fact Sheet 0035-01

This 2-page, illustrated Fact Sheet explains how to read a topographic map and how to determine distance and direction.

Order Fact Sheet 0035-01 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone 1-888-275-8747. Fact sheets are available at no cost. This Fact Sheet also is available on the Web at http://mac.usgs.gov/isb/pubs/factsheets/fs03501.html.

A Topographic Field Trip of Washington, D.C.— A Cartographic Multimedia Application

USGS Fact Sheet 178-99

This multimedia CD-ROM uses topographic maps to tour Washington, D.C. Although designed for the middle-school grade level, it also can be used to teach introductory topographic map reading to any level.

The CD-ROM is an innovative application that displays digital map data to teach students how to read and interpret spatial information. Students relate the map to the real world through the use of sounds, graphics, text, animation, and interactivity. The graphic user interface resembles a video game conroller and functions as an interactive map legend.

Two versions are available. The first version, for Macintosh® systems only, was developed and produced as a prototype with educational resource funds and is available free of charge while supplies last. The second version, for dual platform (Macintosh® and Windows® systems) is a sales item. The dual platform version contains improvements in content and navigational capabilities. It sells for $11.50, plus a $5.00 handling charge per order if purchased by mail. Order from: U.S. Geological Survey, Information Services, Box 25286, Denver, CO 80225; phone 1-888-275-8747.

For more information about this product, refer to USGS Fact Sheet 178-99, available on the Web at http://mac.usgs.gov/isb/pubs/factsheets/fs17899.html.

What Is Ground Water?

USGS Open-File Report 93-0643

Written for a general audience, this 2-page report answers these questions: "How does water get into the ground?", "What is an aquifer?", "Who uses ground water?", "How do you get water out of the ground?", and "Can we run out of ground water?".

Open-File Report 93-0643 is available on the Web at http://pubs.water.usgs.gov/ofr93-643.

Oklahoma abstracts

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Compartmentalization of Overpressured Reservoirs in the Anadarko Basin

ZUHAIR AL-SHAIEB, JIM PUCKETTE, and *AMY CLOSE,* School of Geology, Oklahoma State University, Stillwater, OK 74078

Basin-scale compartments are areas of abnormally pressured reservoirs that are isolated from surrounding normally pressured intervals. This unique configuration evolved by the sealing of abnormally pressured intervals and the maintenance of hydrostatic conditions in the surrounding rocks.

The sealing of the overpressured interval was controlled by distinct mechano-chemical processes that were coincident with basin subsidence. Within the Anadarko basin, these systematic processes resulted in the formation of seals that define the basin-scale compartment termed the mega-compartment complex (MCC). The top of the complex is relatively horizontal, cuts across stratigraphy, and is identified by the first occurrence of abnormally pressured reservoirs. The base of the complex conforms to stratigraphy and follows the Mississippian–Devonian Woodford Shale. Seal formation was directly related to non-equilibrium diagenetic processes that occurred during the rapid subsidence phase of the Pennsylvanian Orogenic episode. The silica cement phase was the major early diagenetic event that initiated a protoseal at depths around 6,000 ft (1,800 m) and a temperature of 60 degrees C. Therefore, the overpressuring of the MCC is directly related to generation of hydrocarbon. With continued burial and heating, fluids migrated toward the lower pressure gradient in the southern bounding fault zone. Precipitation in the vicinity of the fault generated a lateral vertical seal. Convergence of the top and basal boundaries resulted in the complete isolation of the complex.

Normal pressure below the basin-scale compartment was maintained by hydraulic continuity between surface outcrops and subsurface reservoirs. Abnormal pore pressure generated during burial by thermal expansion or other processes was dissipated throughout the reservoir and ultimately equalized with the outcrop-connected hydrostatic regime.

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Sequence Stratigraphic Control on Reservoir Quality in Morrow Sandstone Reservoirs, Northwestern Shelf, Anadarko Basin

JAMES PUCKETTE and *ZUHAIR AL-SHAIEB,* Oklahoma State University, Stillwater, OK 74078

Upper Morrowan valley-fill sandstones are major oil and gas reservoirs on the northwestern shelf of the Anadarko basin. Three major Morrowan lithofacies assemblages were recognized in cores and extrapolated from wire-line log responses: marine, fluvial and estuarine. Primary marine lithofacies are dark fossiliferous shale and bioclastic sandstone. Fluvial facies include channel-lag conglomerates, coarse-grained, cross-bedded sandstones and fine-grained sandstone, siltstone, shale, and coal. Estuarine facies are dominantly fine-grained sandstone and shale with abundant trace fossils.

Incised valleys developed in response to major drops in relative sea level. Lowstand system tract (LST) deposits were not commonly preserved and are limited to a few thin clay-clast conglomerates. Subsequent sea level rises resulted in valley filling with fluvial and estuarine facies of the transgressive systems tract (TST). Continued sea-level rise shifted sediment sources landward and the shelf became a starved margin setting characterized by deposition of marine silt and mud, which represents the highstand systems tract (HST) sediment assemblage. Although, no cores were available, distinct gamma-ray wireline log signatures were interpreted as representing the maximum flooding surface (MFS).

Reservoir quality was influenced by compositional and textural parameters. Secondary porosity is the dominant type and resulted from dissolution of feldspars. Coarser-grained fluvial sandstones with minimal detrital clay retained primary porosity in addition to developing significant secondary porosity. Marine sandstones contain abundant skeletal grains and carbonate cement that occluded porosity. Finer-grained estuarine sandstones are typically poor-quality reservoirs due to high detrital clay content and the affects of biogenic modification that destroyed primary porosity.

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Sequence Stratigraphic Control on Reservoir Quality in Morrow Sandstone Reservoirs, Northwestern Shelf, Anadarko Basin

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Upper Morrowan valley-fill sandstones are major oil and gas reservoir on the northwestern shelf of the Anadarko basin. Three major lithofacies assemblages were recognized in cores and extrapolated from wireline log responses: Marine, fluvial and estuarine. The primary marine lithofacies are dark fossiliferous shale and bioclastic sandstone. Fluvial facies are characteristic of a braided stream channel complex. The complex is further characterized by trough cross bedding containing stacked fining upward sequences, low-angle cross beds and fine- to coarse-grained sandstones and interbedded/laminated with silty, shaly and coal intervals. Estuarine facies are characterized by interbedded fine- to medium-grained sandstones and shales, with abundant trace fossils or burrows.

Incised valley developed in response to major drops in relative sea level. Lowstand system tract (LST) deposits were not

commonly preserved and are limited to a few thin clay-clast conglomerates. Subsequent sea-level rises resulted in valley filling with fluvial and estuarine facies of the transgressive systems tract (TST). As sea level continued to rise, sediment deposition shifted landward. Therefore, deposition of marine silt and mud represents the high stand systems tract (HST) sediment assemblage.

Reservoir quality is controlled by sequence stratigraphic framework coupled with compositional and textural parameters. Braided stream channel complex (F2, F3) deposited during the TST are the best reservoirs observed. The average porosity and permeability is 13.35% and 50.6 md respectively. On the other hand, marine sandstones (M1) contain abundant skeletal grains and carbonate cement-occluded porosity. Fine-grained estuarine sandstones are typically poor-quality reservoirs due to high detrital clay content and the affects of biogenic modification that destroyed primary porosity.

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NMR Relaxation Times and Related Pore Geometry in the Morrow Group (Pennsylvanian), Hemphill County, Texas, and Texas County, Oklahoma

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The Lower Pennsylvanian "Morrow Formation" is a significant oil and gas producer in the Anadarko Basin, Oklahoma and Texas. Basin development is maturing, and continued discovery and exploitation of fields requires refined interpretations based partly on the use of new tools. Nuclear magnetic resonance (NMR) is a wireline tool that, with more accuracy and precision than conventional wireline tools, estimates porosity, permeability, producible fluids and determines the type of formation fluids. The addition of the NMR tool data to conventional wireline tool data aids in reservoir evaluation, furthering the exploitation effort of the Anadarko Basin.

Perhaps the most significant contribution of the NMR tool is its ability to estimate permeability. The field NMR tool uses a magnet 100 times stronger than the Earth's magnetic field to align hydrogen protons with the NMR's magnetic field. This static magnetic field is the B_o field. The tool's antenna then uses a transmitter and receiver to apply in pulses a second magnetic field, the B_1 field, perpendicularly to the B_o field. The NMR tool measures the hydrogen decay once the B_1 pulses are turned off. Evaluation of this "decay-data" allows geoscientists to evaluate complex lithology, identify fluid types and to better study low permeability/low porosity formations.

The bench top NMR machine uses the same principles as the field NMR tool. The bench top NMR machine aligns hydrogen atoms with the static B_o magnetic field. By applying the B_1 field in pulses, protons are excited from a low-energy state into a high-energy state. The machine measures the decay of hydrogen atoms from the B_o and B_1 fields.

In this study, two permeability equations as they apply to NMR data are evaluated in the "Morrow Formation." The first equation, K = (ö/a)^2 * (FFI/BVI)^2, uses the ratio of free fluid to bound fluid to estimate pore sizes (where ö = porosity, either from NMR readings, conventional log readings or core analysis [generally all are equivalent]; a = a constant, usually 10 for sandstones; FFI = free fluid index and BVI = bound fluid index, FFI/BVI ratio calculated using a 33 msec cutoff). This equation is normally applied in the field. The second equation, K = a * ö^4 * T_2^2, uses the T_2 value to estimate pore size (where a = a constant, usually 4 for sandstones and the T_2 value is taken from NMR lab measurements). Besides using the T_2 value from lab measurements, a T_2 value can also be weighed against changes in the NMR curve. This weighed T_2 value generally correlates better to pore size than the lab measured T_2 value.

Results of comparing data from the two permeability equations to measured core permeability indicate that, in the "Morrow Formation," the FFI/BVI equation underestimates permeability and the T_2 equation overestimates permeability. As a result of this disparity, the purpose of this study is to adjust the exponents and constants in the permeability equations such that calculated permeability more accurately and precisely correlates to observed permeability, better allowing geoscientists to evaluate the "Morrow Formation."

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Depositional History and Reservoir Characterization of the Northeast Hardesty Field, Texas County, Oklahoma

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The Northeast Hardesty Field in the Oklahoma Panhandle was developed in the late 1950s and produces oil from the Morrow Formation. The Upper Morrow fluvial channel fill sandstones form prolific hydrocarbon reservoirs, however, lack of vertical and lateral continuity, grain size variation, rapid facies changes and diagenesis have hindered development projects.

The Upper Morrow "A" was deposited in an incised valley in response to fluctuating base level. The Mid-continent region was tectonically active from late Mississippian to early Pennsylvanian time. Slight tectonic fluctuations initiated changes in stream gradient. The complex style of deposition from both braided and meandering streams is a result of changes in regional structure during deposition.

Distinctions between braid bars deposited by braided streams and point bars deposited by meandering streams are made based on sedimentary structures observed in cores. Braid bars are commonly massive to cross-stratified or structureless, poorly-sorted and poorly-organized. Common features include pebble sheets, mudstone clasts altered to siderite, and carbonized organic debris. Grain size ranges from coarse to very coarse and pebbly with gravel found at the base. Point bar deposits are characterized by cross-stratified to planar or ripple lamination and are well-organized and well-sorted. Silty, micaceous drapes are common throughout the deposits. Grain size ranges from silt to medium-grained sand with pebbles found at the base.

Diagenesis has severely impacted the reservoir quality of the Upper Morrow sandstones in the Northeast Hardesty area. Porosity and permeability have been affected by cementation, compaction, natural dissolution of chemically unstable detrital grains and authigenic cements, and clays that fill pores and clog pore throats. Although the Upper Morrow "A" sands appear to be attractive reservoirs, diagenesis has drastically reduced reservoir quality.

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3C-3D Seismic Characterization of the Eva South Morrow Sand Unit, Texas County, Oklahoma

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A 3-component, 3-dimensional (3C-3D) high-resolution seismic survey was acquired over the Eva South Morrow Unit in T3N-R11ECM of Texas County, Oklahoma, to characterize the producing Upper Morrow sandstone reservoir which is currently under secondary recovery by waterflood. The ultimate goal of this characterization was to identify reservoir extents and possible compartmentalization in order to plan additional drilling to increase the ultimate secondary recovery of the field and prevent premature abandonment. This project was funded in part by a grant from the Department of Energy through the Reservoir Class Field Demonstration Program-Class Revisit.

Three component recording was utilized with a standard, vertical component, vibroseis source to capture both compressional wave (P) and converted mode shear wave (P-SV) information. Using P-SV waves to obtain shear wave seismic information was advantageous in that it did not require the significant added expense of mobilizing a shear wave source in addition to the compressional source. Excellent structural definition of the bounding fault system to the field was achieved which illustrated its complex nature. The overall valley system geometry and gross reservoir sandstone distribution were imaged with both the P and P-SV seismic data, and further analyses and processing of the data are being done to further enhance the reservoir interpretation.

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Reservoir Characterization and Development of Valley Fill Deposits with 3C3D Seismic and Horizontal Drilling, Eva South Morrow Sand Unit, Oklahoma

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The Eva South Morrow Sand Unit (ESU) was selected as a demonstration site to test the ability of 3C3D seismic and horizontal wells to improve reservoir characterization and sweep efficiency in a waterflood unit. This project was supported in part by a grant from the U.S. Department of Energy under the Reservoir Class Field Demonstration Program-Class Revisit.

ESU produces from transgressive valley-fill deposits of the Morrow. The trap is formed by a convex up-dip bend in the valley system. Cores show that the reservoir is composed of very coarse grain, planar- to cross-bedded, fluvial sandstone. Non-reservoir facies include mudstone and shale deposited in abandoned channel and flood plain environments. At least four compartments have been identified that interfere with reservoir sweep efficiency. Compartmentalization and reservoir heterogeneity is caused by faulting and abandoned channel-fill deposits.

A 4.25 square mile 3D seismic survey was obtained over the field. In addition to the standard P-wave data, mode-converted shear-wave data was recorded in an effort to improve resolution of the reservoir sandstone. The P-wave data provided excellent definition of the structure in the field, good definition of the valley-system and fair definition of the reservoir sandstone. The shear-wave data provided good definition of the faulting and a slight improvement over the P-wave data in the definition of reservoir sandstone. New processing techniques are being developed in an effort to improve the resolution of the shear-wave data. To date, one new horizontal well has been drilled with encouraging production results.

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Upper Mississippian (Chester) Ooid Shoals: Austin Upper Mississippian Field, New Mexico, and Mocane-Laverne Field, Oklahoma, and their Relation to North American Chester Paleogeography

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Upper Chester ooid grainstones produce gas in both the Austin Upper Mississippian Field in Lea County, New Mexico (13 BCF + 130 MBO) and the Mocane-Laverne Field in Harper and Beaver Counties, Oklahoma (703 BCF). These ooid grainstone were deposited in an upper Chester HST due to a loss of accommodation space. The reservoirs in both fields are skeletal ooid grainstones with intergranular porosity.

The ooid grainstones in southeast New Mexico were deposited as a series of northeast-southwest oriented elongate ooid shoals perpendicular to the Chester shelf margin. In the Mocane-Laverne Field the Chester ooid shoals exhibit a similar geometry, but are oriented northwest-southeast also perpendicular to the Chester shelf margin. The orientation of the Chester ooid shoals perpendicular to the shelf margin is similar to the orientation of modern ooid tidal bar belts at the end of the Tongue of the Ocean in the Bahamas. Chester ooid grainstones have also been reported in southwest New Mexico, West Texas, north-central Texas, southwest Kansas and north-central Arkansas (Pitkin Limestone) plus the Illinois and Appalachian basins. Therefore, south of the Mississippian paleoequator Chester ooid shoals may have extended across southern New Mexico around the Texas Peninsula into Oklahoma across to Arkansas all the way to the Appalachian Basin deposited along the upper Mississippian shelf margin a distance of over 2,600 miles.

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Finding New Pays in Old Plays: New Applications for Geochemical Exploration in Mature Basins

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Detailed geochemical surveys document that hydrocarbon microseepage from petroleum accumulations is common and widespread, is predominantly vertical, and is dynamic. These characteristics create a new suite of applications for surface geochemical surveys: field development, finding by-passed pay, and monitoring hydrocarbon drainage. Because hydrocarbon microseepage is nearly vertical, the extent of an anomaly at the surface can approximate the productive limits of the reservoir at depth. The detailed pattern of microseepage over a field can also reflect reservoir heterogeneity and distinguish hydrocarbon-charged compartments from drained or uncharged compartments. Additionally, since hydrocarbon microseepage is dynamic, seepage patterns change rapidly in response to production-induced changes.

Evidence for such changes are documented with detailed microbial and soil gas surveys from Texas, Oklahoma, and Kansas. When such surveys are repeated over the life of a field or waterflood project, the changes in seepage patterns can reflect patterns of hydrocarbon drainage. Applications such as these require close sample spacing, and are most effective when results are integrated with subsurface data, especially 3-D seismic data. The need for such integration cannot be overemphasized. High-resolution microseepage surveys offer a flexible, low-risk and low-cost technology that naturally complements more traditional geologic and seismic methods. Properly integrated with seismic data, their use has led to the addition of new reserves, drilling of fewer dry or marginal wells, and optimization of the number and placement of development or secondary recovery wells.

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Exploring for Petroleum in the Flatlands: History of Oil and Gas Exploration in Kansas

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The history of any subject is best told through the sequence of events and those who partook in them. Exploring for the elusive petroleum trap in the flatlands of the Midcontinent, and Kansas in particular, is no exception. Hints of petroleum in the area were seeps or "tar springs," known by the Native Americans, who used it for medicinal purposes. In the 19th Century travelers on the cross-country emigrant trails used petroleum as a lubricant for their wagon wheels. By the turn of the 20th Century, crude oil and natural gas were in demand and thus the quest was on for the hidden treasure. Early exploration was essentially random drilling, but "trendology" or "creekology" soon caught on. Mapping subtle structure in low-dip sedimentary beds proved difficult, but not impossible. As sophistication of the techniques increased, the success ratio improved. Planetable mapping was followed by core drilling and then the seismograph. Many companies had their origin in southeastern Kansas and northeastern Oklahoma as well as some of the future giants in the industry including Wallace Pratt, Alex McCoy, and Hollis Hedberg. The Kansas Geological Survey, created just four years after the discovery of petroleum in a well drilled near Paola in Miami County in 1860, was an active participant in this quest, providing data and ideas to the seekers, as was the U.S. Geological Survey. The work of Erasmus "Daddy" Haworth, third state geologist of Kansas, was instrumental in locating the giant El Dorado oil field in 1914. For more than a century the Kansas Survey has provided a service to the petroleum industry in the State.

Impetus for an oil boom in southeastern Kansas came in 1894 with discovery of oil in Mississippian rocks in the Forrest No. 1 Norman well at Neodesha.

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Oklahoma and the Petroleum Industry: An Enduring Partnership

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The Nellie Johnstone #I discovered commercial quantities of petroleum in 1897, and that set off a frenzy of drilling activities in Oklahoma and Indian Territories, an area that later became Oklahoma. In the next ten years, production increased to more than 43 million barrels per year, making Oklahoma the largest oil-producing entity in the world at Statehood in 1907.

From the beginning, the fortunes of Oklahoma and that of the petroleum industry in the State were intertwined. Small operators with large discoveries soon became large companies, and a number of the major companies can trace their roots to these early days in Oklahoma.

This activity in Oklahoma also spawned the need for scientific and professional organizations. The American Association of Petroleum Geologists (AAPG) was established in 1918 in Tulsa. The Society of Economic Paleontologists and Mineralogists (SEPM) was founded in 1926 as a division of AAPG. The Society of Exploration Geophysicists began as a division of AAPG in 1930.

Philanthropy became an important activity for many who made their fortunes in the petroleum industry. The long list of museums, hospitals, educational institutions, libraries, parks, and foundations is a lasting tribute to these amazing men and women that "brought Oklahoma to the dance" at Statehood.

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An Overview of the Seismic Characteristics of Layered Sequences of the Precambrian Basement of the Southern Mid-Continent

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Seismic reflection data that image buried Precambrian rocks of the southern mid-continent commonly exhibit layering that recent work suggests has a variety of different origins. Layering beneath the Hardeman Basin of Oklahoma and Texas, first imaged in COCORP data in the 1970s, is characterized by two or three very strong reflection packages against which lower amplitude reflections truncate in downlap or onlap geometries. Packages of strong reflections are also found beneath the Palo Duro Basin of the Texas Panhandle. Data from this region shows downlap and onlap against the strong reflectors as well as crosscutting relationships among the strong reflectors. Thus, while data from the Hardeman Basin might favor a sedimentary origin, data from the Palo Duro Basin are suggestive of an igneous origin. Drill hole data, and recent geochemical and geochronologic data point to an episode of bimodal igneous activity at ~1.3 Ga, that likely included intrusion of mafic sills and deposition of volcanoclastic strata, as the origin of the reflectivity. In the central Permian basin, along the Texas–New Mexico border, and in the Tucumcari basin of New Mexico, basement reflectivity is due to extensional activity at 1.2 to 1.1 Ga. Seismic data from the central Permian Basin exhibits pervasive layering over a large area, that is clearly correlated to a

~1.1 Ga massive layer intrusion, termed the Pecos Mafic Intrusive Complex (PMIC), on the basis of a synthetic seismogram from the North American Royalties #1 Nellie well which penetrated 4 km of the intrusion. Further north in the Tucumcari basin, seismic data show that the metasediments and the metavolcanics of the ~1.2 Ga Debaca-Swisher terrane unconformably overlie basement that is probably comprised of ~1.3 Ga felsic rocks. Well data suggest that strong subhorizontal reflectors in this package are due to mafic sills. New geochemical and geochronologic data from wells that penetrate basement in eastern New Mexico and the Texas Panhandle has been a major contributor to a more detailed understanding of the origin of reflectors in the southern mid-continent.

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The Cambro–Ordovician Signal Mountain Formation—An Arbuckle Group Enigma

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The Signal Mountain Formation (SMF), second oldest Formation in the Cambro–Ordovician Arbuckle Group of Oklahoma, rests unconformably on the Fort Sill Formation, the unconformity recording a craton-wide regression. Subsequent transgression coincided with rapid redefinition of the Southern Oklahoma aulacogen as a discrete linear deeper water "gulf" within the Laurentian carbonate platform. Lithologies include bioturbated and poorly sorted intrapelbiomicrites, poorly sorted biosparites, mudstones and intraformational conglomerates. Individual beds are from 1 to 5 cm thick, show little systematic ordering and were deposited in marine, aphotic, below wave base settings; density and turbidity flows contributed to the sediments. Some rocks were deposited in seafloor anoxia; they lack bioturbation, and are fine grained, laminated pelbiomicrites and thin (<2 in. [5 cm]) black shales that contain ~1% total organic carbon. The section presents evidence, in the form of tectonic veining, stylolites that partitioned the movement of cementing fluids, early small scale faulting and rotated lenticular carbonates, that suggest an early tectonic imprint. This imprint coincided with the tectonic redefinition of the Southern Oklahoma aulacogen. Later bedding-parallel stylolites are a response to deep burial, at ~3,000 m for ~140 million years, while later complex vein fills record Pennsylvanian inversion and dilation.

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Geologic Evolution of Proterozoic Rocks, Eastern and Southern Midcontinent of United States

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Upper crustal Proterozoic rocks in the eastern and southern midcontinent of the United States are part of the Transcontinental Proterozoic province and consist mainly of epizonal to mesozonal granite and related rhyolite, immature to mature sedimentary rocks, and widespread late diabase dikes and sills. Major element, trace element, and isotopic ratios of the felsic and mafic igneous rocks record the geologic and tectonic environment in which they formed. Felsic igneous rocks in most of the region have mainly A-type chemical affinities and accumulated in a within-plate tectonic environment. Toward the south in the Arbuckle Mountains and adjacent regions, 1,400–1,350 Ma granitoids have a calc-alkaline geochemical signature, suggesting they formed within a magmatic arc along the southern margin of Laurentia. Late diabase dikes and sills have geochemical characteristics of continental within-plate tholeiites.

The main granite-rhyolite igneous suite implies magmatism associated with extension in Middle Proterozoic time, probably during the development of regional and local continental basins within zones of subsidence. Consistent with this interpretation is the presence of basinal Proterozoic sedimentary rocks that accumulated beneath or within the granite-rhyolite sequence, sheet-like mature sedimentary deposits, and immature sedimentary strata that are associated with basaltic and diabasic rocks that formed as rifting caused further extension.

Prominent and thick seismic layered units in parts of Illinois, Indiana, Ohio, and Panhandle Texas support the presence of Proterozoic basins in the midcontinent. The layering probably reflects these basinal strata and the diabase dikes and sills. The layered sequence may be analogous to thick accumulations of Proterozoic supracrustal rocks that are notable in reconstructions of the Proterozoic North Atlantic shield.

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How Seismic Ray Trace Modeling Can Enhance the Interpretation of Seismic Data from Complex Subsurface Structures: An Example from the Wichita Mountains Frontal Zone, Southern Oklahoma

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The Wichita Mountain Front (WMF) is part of the linear trend in southern Oklahoma that extends from the Arbuckle Mountains in south central Oklahoma through the Wichita Mountains to the buried Amarillo Mountains in the Texas Panhandle. Intense subsurface deformation exists along the WMF, including overturned beds and crystalline basement rocks thrust over Paleozoic sedimentary rocks. Dipmeter data indicate 180° changes in dip direction. Correct migrations of seismic data are vital to accurate interpretations, but they cannot be achieved without well-defined velocity models. Velocity models are in turn based on interpretations of the data. Seismic ray tracing can confirm or discredit an interpretation. Accurate interpretations are a prerequisite to improving exploration successes.

A synthetic seismic data set paralleling an actual seismic line was created with ray-tracing software by building a viable cross section using all available data, including well data and seismic data. X, Z horizon coordinates, layer velocities, and ray propagation parameters (such as attenuation coefficient, and generation of shear or compressional rays) are specified. Ray paths were calculated and analyzed to determine where reflections occurred in the subsurface and their corresponding CMP location. Arrival times and reflection amplitudes were convolved with a wavelet to produce synthetic traces for comparison to actual seismic data.

Two alternate velocity models were constructed to demonstrate that a lack of data, or an inaccurate interpretation produce ambiguous results. The synthetic data set was migrated with the exact velocity grid used to create the data and then the data set was migrated with the alternate velocity models. Comparing the three resulting migrations to the actual seismic data confirmed that the more accurate migration velocity model produced the clearest result. The most accurate migration, however, still does not accurately position all reflection events.

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Using Emplacement Position to Help Constrain Origin of Granites

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The granite exposures in the Wichita Mountains of southwestern Oklahoma are some of the uppermost outcrops of the Cambrian Southern Oklahoma Aulacogen (SOA). This aulacogen is characterized by a close interplay between rifting and magmatism, so that each magmatic pulse is taken to be coincident with a new pulse of extension. The granites were emplaced near the end of the rifting event. The rift zone retains enough stratigraphic and structural history so that portions of its magmatic filling can be documented and leads to the following interpretive scenario.

Eleven mappable granites exist over an area of about 30 × 100 km. They have all been shallowly intruded along an unconformity between underlying layered mafic complex(es?) (e.g., Glen Mountains Layered Complex) and an overlying rhyolitic sequence (Carlton Rhyolite). The granites are all A-type sheet granites which generally do not overlay but abut one another. Isotopic data indicate that some granites are primarily differentiates of mafic mantle magmas while others have heterogeneous crustal sources.

However, because the rising granitic magmas stopped at the same upper crustal discontinuity, their driving pressures must have been comparable whatever the source. This necessitates either (1) that the crustal zones from which differentiation took place and where adjacent crustal melting occurred were at the same crustal level, or (2) that wherever the magmas formed, they ascended and ponded at the same mid-crustal level before finally moving on upward to their emplacement positions.

Thus, in such situations it would make sense to search for petrologic/mineralogic indicators on source depth, or geophysically for discrete horizons of magma sourcing or ponding. For the SOA there are clues that help constrain the granite source levels to mid-crust.

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Stratigraphic Variation in Oxygen and Carbon Isotope Composition Within One Glacio-Eustatic Pennsylvanian Cyclothem in Midcontinent North America

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The typical midcontinent Iola cyclothem consists of the basal transgressive Paola limestone, overlain by the offshore dark Muncie Creek Shale, in turn overlain by the regressive Raytown Limestone. We analyzed outcrop and core samples from carbonate-mud matrix of the two limestones, in a shoreward to basin transect from Iowa to Oklahoma.

In basinward sections carbon isotope values start at ~0‰ at the base of the Paola, increase to ~2‰ immediately below and above the offshore shale, and continue to increase in the Raytown to values ranging from 3.5 to 5‰. In the shoreward sections carbon isotope values range from –5 to 0‰ in the Paola and in the Raytown immediately above the offshore shale, and from 0 to 2‰ higher in the Raytown. The most shoreward Raytown ranges from ~0.4‰ near the base and gradually depletes to about –2‰ at the top. Oxygen isotope values in the basinward sections typically range from about –8 to –5‰, except for one section, where average values are consistently ~2‰ heavier. In the shoreward sections, oxygen isotope values range from –6 to –3‰.

The carbon isotope enrichment in basinward Paola indicates that carbon sequestration was initiated during Paola deposition, and continued through Raytown deposition. Three alternative scenarios could account for the dissimilarities between basinward and shoreward signals in this cyclothem. (1) Diagenetic overprinting in the shoreward sections, causing negative carbon towards the top, and masking the positive carbon excursion preserved in the basin; (2) More basinward Paola is younger than shoreward Paola, and Muncie Creek blankets Paola; (3) Continuity of $\delta^{13}C$ enrichment unperturbed from Paola into Raytown suggests either that significant time did not elapse during Muncie Creek shale deposition, or that the Muncie Creek is time transgressive. Detailed analysis continues in an attempt to resolve among these alternatives.

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Accretionary Basement Control on Structure of Central USA

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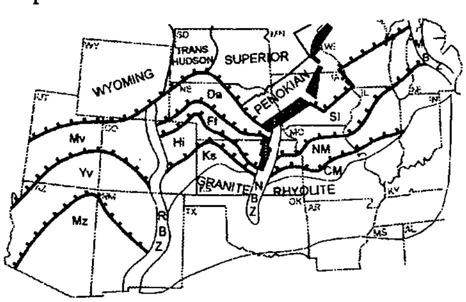
A series ot accretionary terranes created the southward growth of North America during the Proterozoic. Their sutures, and the intervening boundary zones, established the rejuvenation pattern for Phanerozoic structures. The three series of accretionary terranes and their suture ages (Ga) are: the Southwestern Series consisting of the Mojave (Mv, 1.75), the Yavapai (Yv, 1.70) and the Mazatzal (Mz, 1.65); the Southern Series consisting of the Dawes (Da, 1.78), the Frontier (Ft, 1.71), the Hitchcock (Hi, 1.67) and the Kansas (Ks, 1.61); and the Southeastern Series consisting of the Southern Iowa (SI, 1.76), the Northern Missouri (NM) and the Central Missouri (CM). The intervening Boundary Zones are the Rockies (RBZ), the Nemaha (NBZ) and the Michigan (MBZ) each of which formed a broad north-south suture susceptable to later reactivation structures.



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