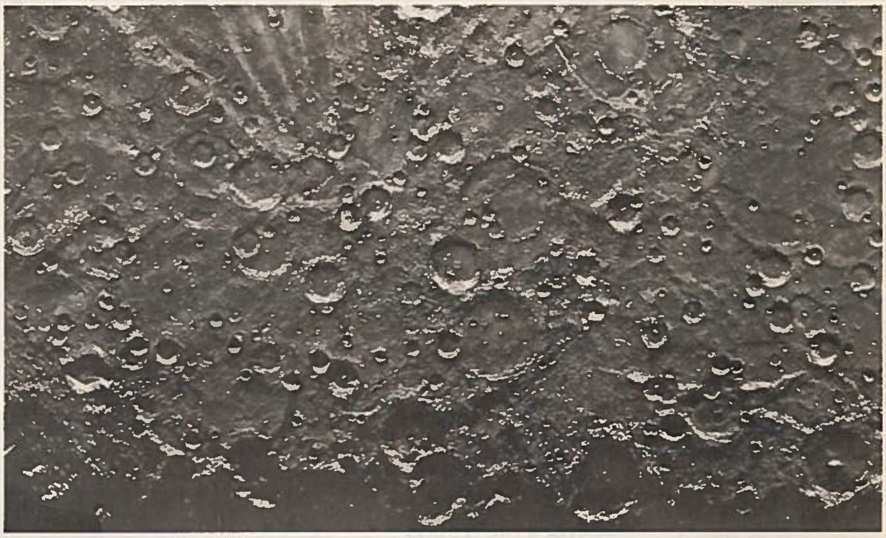
Impact craters: implications for basement hydrocarbon production

The impact cratering process results in unique structures and extensive fracturing and brecciation of the target rock which can be conducive to hydrocarbon accumulations in both sedimentary and crystalline rock.

Impact cratering estimates on the terrestrial land surface for the past 3 billion years predict over 150,000 craters having diameters of 1 km or larger. Preservation age studies of recognized impact sites imply that many craters will have been buried before errosional eradication; as with normally fractured basement areas flanked or overlain by source rocks, some will have accumulated hydrocarbons. Core analysis from large basement impact sites reveals that their potential reservoir volume exceeds many of the largest known hydrocarbon accumulations.



Mariner photo of Mercury showing extensive cratering features.

As the expanded search for oil and gas continues, it becomes imperative for geologists to recognize the dynamic forces from outside the earth that have modified petroliferous basins.

Economic significance. The Boltysh depression in the Ukraine S.S.R. has been recognized as a fossil meteorite crater and is well known as a locality for oil shales, the reserves of which account for about 3 billion tons. A number of other possible impact structures associated with mineral deposits in the Ukraine are being investigated.

In addition to the mineral resources of Sudbury, a Canadian probable impact crater containing over 75% of the western world's nickel deposits, several commercial hydrocarbon bearing structures in North American are suspected as being of impact origin.

These are the Viewfield, Red Wing Creek, and Newporte structures in the Williston basin. Three additional curious subsurface features currently are under investigation in two southern U.S. basins.

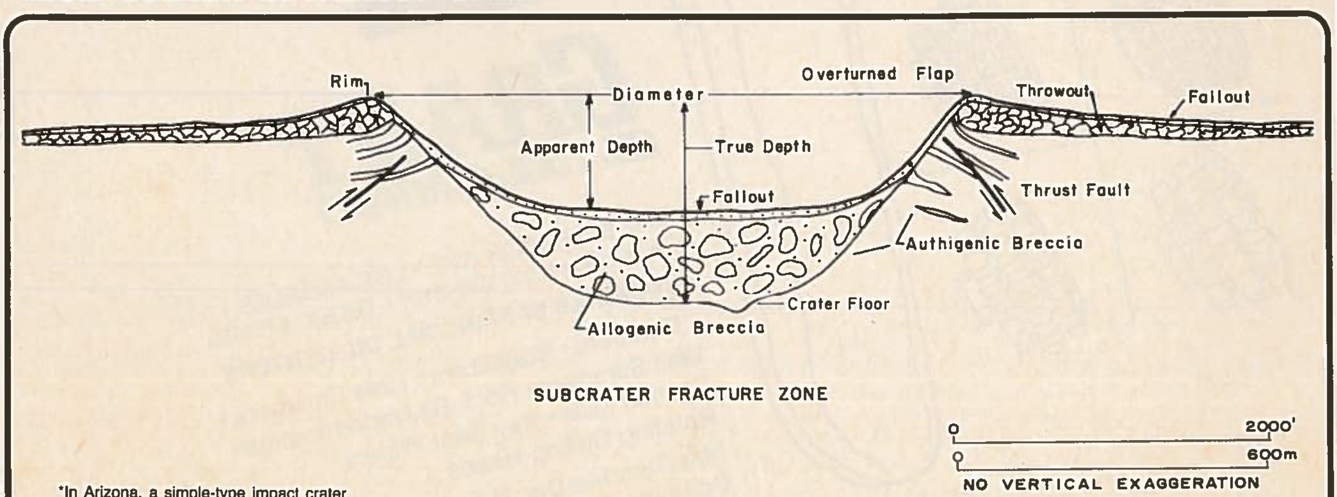
Morphology. Two basic classes of impact craters (astroblemes) have been recognized on the earth and other planetary bodies—the simple and the complex.

The simple craters are characterized by a bowl shaped depression and a raised and overturned rim, a classical example of which is meteor crater in Arizona (Fig. 1). This feature is developed in sedimentary rocks and is about 1.2 km in diameter, 180 m deep, and has a raised rim of about 40 m.

At a crater diameter of about 4 km in crystalline rock and 2-3 km in sedimentary rock, a morphological change from simple to complex type occurs (Fig. 2), which results in a

Fig. 1

Cross-section of Meteor Crater*



*In Arizona, a simple-type impact crater (modified from Shoemaker and Eggleton, 1961).

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Fig. 2

Diagrammatic cross-section*

*Of a complex-type impact crater (Brenan e t al.)

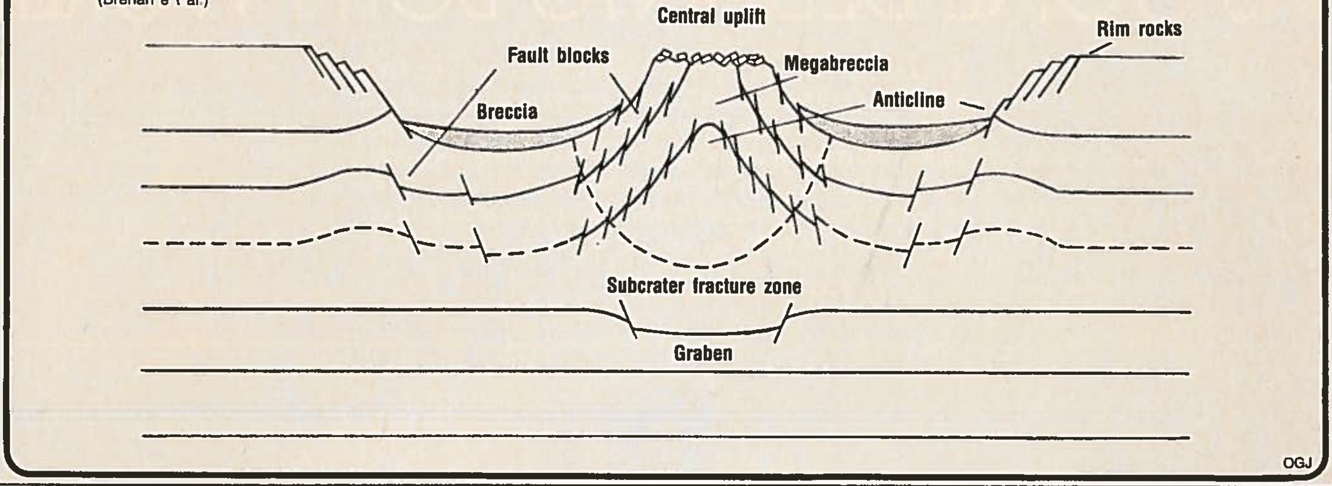
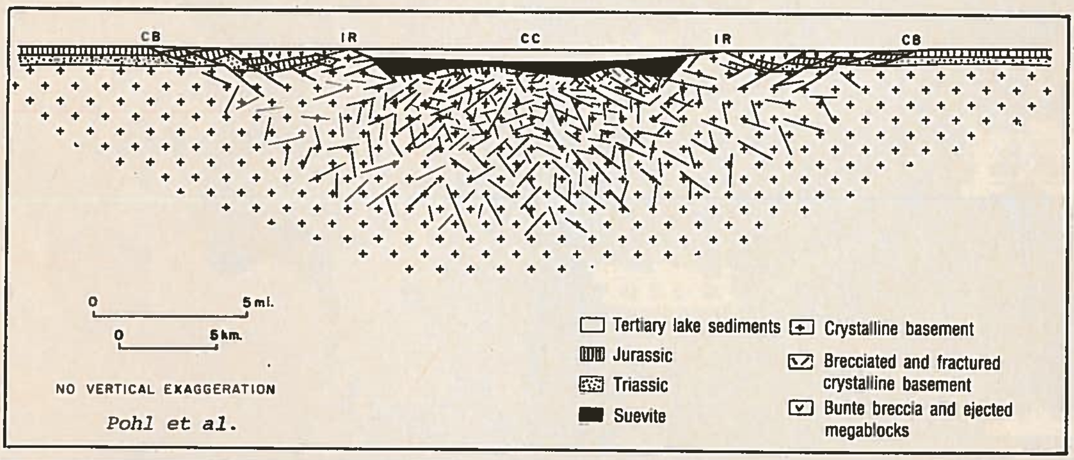


Fig. 3

Profile of Ries Crater

CC is crater center, IR is inner ring, CB is crater boundary



comparatively shallow crater having an uplifted central area or peak and a slumped or depressed rim.

Generally, complex structures up to about 30 km diameter will have distinct peaks or uplifts. Beyond this diameter, the central uplift may be replaced or augmented by a concentric series of uplifts and depressions, giving the structure a multiring form.

By convention, a suspected impact crater in which meteoritic fragments have been found is classified as proved. If only shock metamorphic features are detected, the crater is classified as probable. Any other criteria used in suggesting an impact origin such as structure, classify it as possible. The cumulative number of proved, probable, and possible impact craters on earth now stands at 145. These include both surface and subsurface craters, many of which have only recently been recognized. The number of suspected impact sites continues to increase as geologists become more familiar with cratering mechanics and shock metamorphism.

The latter term describes all changes in rocks and minerals resulting from the passage of transient high pressure shock waves. These changes are distinct from normal terrestrial processes and result in high pressure, high strain rate and high temperature effects. Some of these effects include the production of coesite, stishovite and diamond planar features in quartz, feldspar glass, and the decomposition of sircon to baddeleyite. Unusual conical fracture surfaces called "shatter cones" are often formed within impact sites as well.

Effects on target rock. The impact process has important implications for petroleum geology in that an impact can instantaneously create porous and permeable rock from nonreservoir material and also modify the structural configuration of the target rock independently of the regional geology.

With large magnitude impacts the extent of these alterations is tremendous.

At the Ries basin in Germany (Fig. 3), the hypervelocity impact of an estimated 1 km diameter stony meteorite penetrated about 600 m of sedimentary sequence and continued for another 650 m into crystalline basement. The ensuing explosion excavated between 124 cu km and 200 cu km of rock, and produced a complex ringed crater 22-23 km in diameter. Seismic measurements have revealed that basement rock at the crater center has been brecciated and fractured down to about 6 km.

The potential for structural and stratigraphic traps created by the impact process is readily seen in Figs. 1 and 2. Under proper conditions, both simple and complex type impact craters have a significant potential as hydrocarbon reservoirs. This potential can be appreciated by briefly examining several petroliferous structures suspected as being of impact origin, two of which are developed in sediments and one which is proposed to be a crystalline basement astrobleme. All three are found in the Williston basin, where "pancake" stratigrphy often facilitates the detection of many subsurface structural anomalies.

Viewfield. This oil pool was discovered in 1969 after a routine seismic survey indicated the presence of a subtle circular shaped anomaly.

Subsequent well control has shown that the feature is composed of three principal elements:

1. A deep cavity cut into Mississippian carbonates which has been filled by an anomalously thick Jurassic Watrous Red Bed section (Fig. 4).
2. An oil bearing Mississippian carbonate breccia which forms a rim facies around the central cavity and is located at the Waltrous Red Beds time stratigraphic level (Fig. 5).
3. Mississippian beds which surround the cavity and rim facies. Oil bearing Griffin beds are located at the Mississippian unconformity over most of the area; the underlying Stoughton beds are also oil productive in certain areas.

The rim facies isopach reveals an irregular lobe like pattern radiating outward from the central cavity, with highest isopach values generally found midway between the inner and outer 0 ft contour intervals. It is interpreted to slump towards the central cavity and, in the 13-33 and 14-20 wells, lies between the same red beds filling the central depression near the 15-29 location (Fig. 4). Pay thickness in the rim ranges from 12-170 ft with some wells producing up to 400 bo/d. Core analysis of the breccia from these wells has shown an average porosity of about 14% and an average permeability of about 400 md. The rim facies is stratigraphically trapped by anhydrite and siltstone.

Adjacent to, and in some areas underlying, the rim facies is the oil bearing Mississippian Griffin carbonate. Oil accumulation in these beds is largely unrelated to the Viewfield structure and the trapping mechanism is due to erosional truncation of the Griffin beds updip to the north. These beds are secondary objectives, with pay sections ranging from 15-55 ft.

Original oil in place of the structure exceeds 75 million bbl of which about 20 million are recoverable. No wells have penetrated the Mississippian interval below the central depression.

This feature appears to have formed independently of the regional tectonics and has the characteristics of a simple type crater. The breccia, or talus, which forms the rim facies, however, may have been created following the impact event. Crater rims are formed by overturning of the target rock which, if brittle, can be fractured, but not usually brecciated to the degree shown in the Viewfield cores. If left uncovered, rim rocks will be eroded in a similar manner as any hill or elevated structure, however, and can become breccia or talus deposits.

Shock metamorphic features have not yet been detected, presumably

Fig. 4

Cross-section of Viewfield

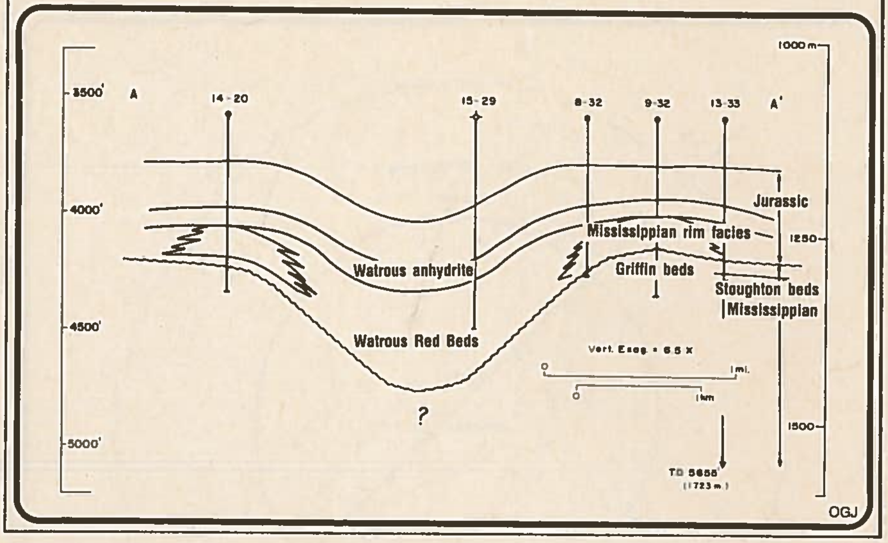
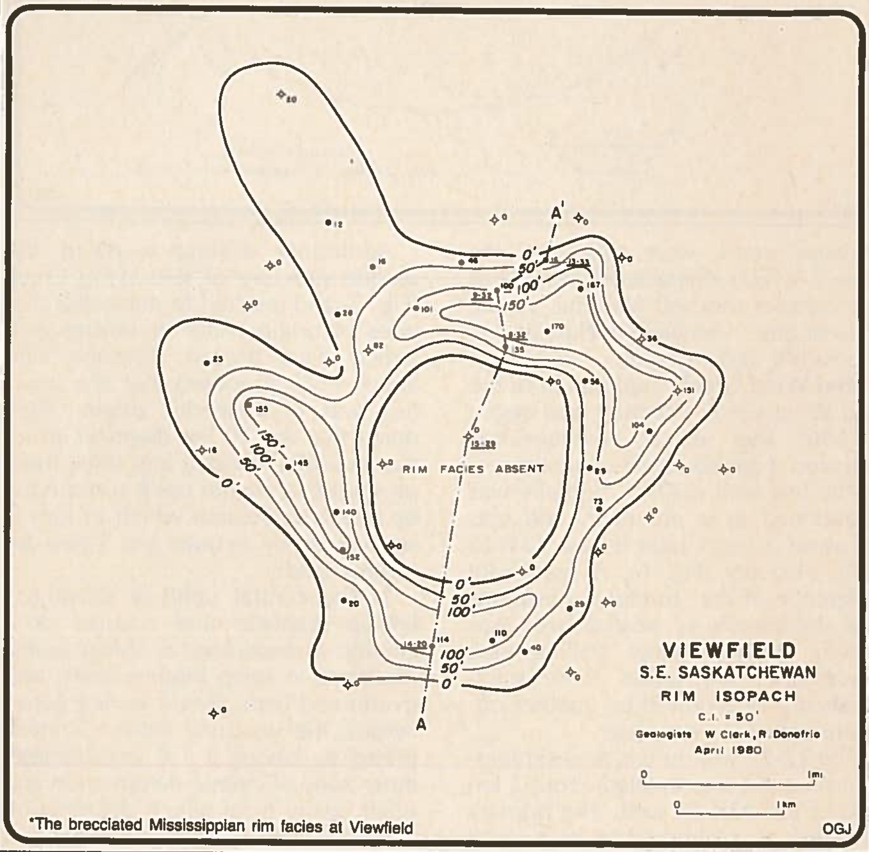


Fig. 5

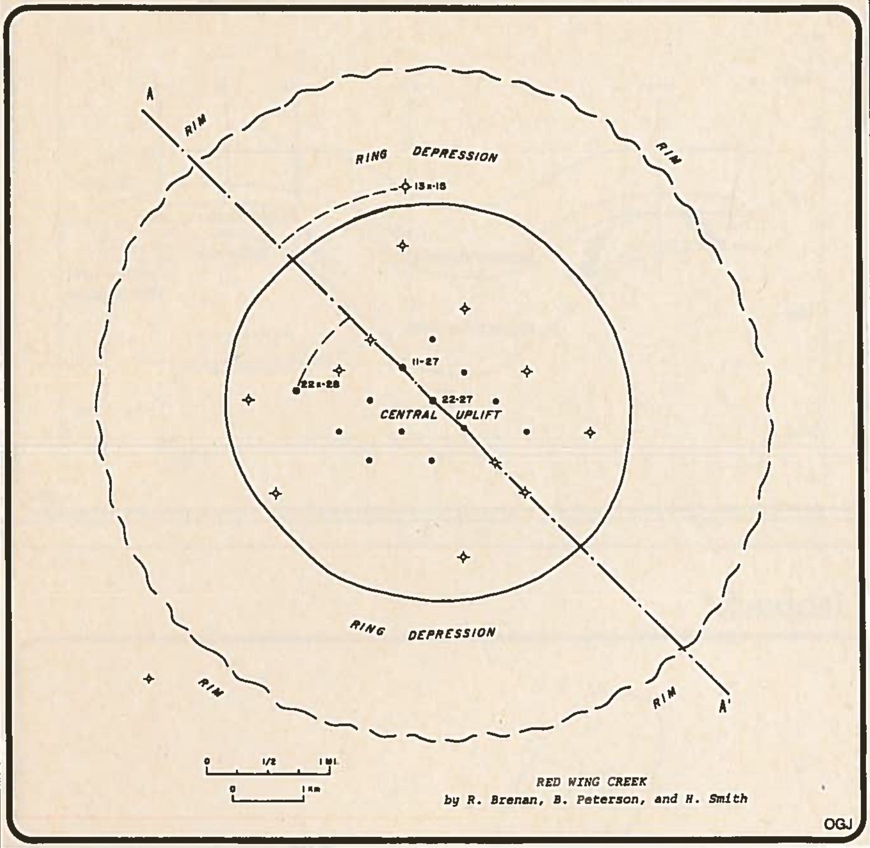
Isopach*



*The brecciated Mississippian rim facies at Viewfield

Fig 6

Plan view of Red Wing Creek



because cores were taken in the "rim," which characteristically does not contain shocked material. At the present time, Viewfield is classified as a possible impact crater.

Red Wing Creek. Exploration of the Red Wing Creek structure was begun in 1965 after seismic coverage had revealed a pronounced anomaly.

The first well, 22X-28, initially was abandoned as a dry hole, and was followed 3 years later by the 13X-15 well, also dry (Fig. 6). A significant difference in the structural elevations and thicknesses of several beds was noted, but no further drilling took place until the leases were relinquished and acquired by another operator about 4 years later.

The 22-27 well in this new exploration program was located about 2 km east of the 22X-28 well. The primary objective was rumored to be a small Ordovician structure believed to be present beneath an anomalous seismic zone interpreted as an area of intensive deformation. En route to the Ordovician, the well found an 823 m (2,700 ft) oil column in the Mississippian, 487 m (1,600 ft) of which was net pay. An initial production tested in the brecciated carbonate flowed 750 bo/d, 41.8° API. The Ordovician "structure" turned out to be a velocity anomaly.

Additional drilling revealed the unique structure of Red Wing Creek (Fig. 7) and resulted in numerous theories of origin. After reviewing geological data, Brenan, Peterson, and Smith 9175 proposed that the structure was of meteoritic origin. They noted that the 10 km diameter structure could be divided into three main provinces: a central uplift surrounded by a ring depression which in turn is surrounded by an outer rim. These are summarized:

1. The central uplift is about 6.5 km in diameter and consists of a chaotic arrangement of thrust faults, moderate to steep dipping beds, and overturned beds. Based on log correlations, the structural pattern is interpreted as having a 1.6 km diameter inner zone of intense deformation and uplift, away from which deformation decreases in both horizontal and downward directions. Within this area of maximum deformation which has created a megabreccia, Mississippian carbonates have been thrust as much as 915 m above regional subsurface elevation. The main productive area of the structure is confined to this megabreccia. The original 22X-28 "dry well," however, is an exception; it was later recompleted as an oil well by another operator.

2. The ring depression is a syncline or graben which surrounds the central uplift. It is about 1.6 km wide and is bounded by deformed rocks of the outer rim. The principal deformation evident in the ring depression is normal faulting, with fault blocks having moved inward towards the central uplift as well as downward. Displacements in the upper horizons range from 175 to 115 m below expected regional elevations, and as much as 975 m below equivalent formations in the central uplift.

3. The outer rim surrounds the ring depression and is composed of mildly deformed rocks. Formations in this area are 90-185 m structurally higher than their equivalents in the ring depression. A discontinuous narrow anticline with 45-60 m of closure parallels the boundary between the rim and ring depression. Seismic investigation has shown that it has a width of less than 1.6 km at its widest location.

The Red Wing Creek structure can be classified as a probable complex crater, since the requisite shock metamorphic features have been detected in drill cores and cuttings. These features include distinct shatter cones and radiating concussion fractures in quartz grains. The impact age at Red Wing Creek is Jurassic-Triassic, and the size of the crater precludes survival of meteoritic fragments, thus preventing a proved impact crater designation.

Calculations show that the central uplift megabreccia has trapped in excess of 130 million bbl of oil, virtually all of which is confined to a 1.6 km diameter area. Recoverable reserve estimates range from 40-70 million bbl. Additional pay zones are possible in this type of crater because of secondary structures resulting from vertical and horizontal deformation of the main producing interval.

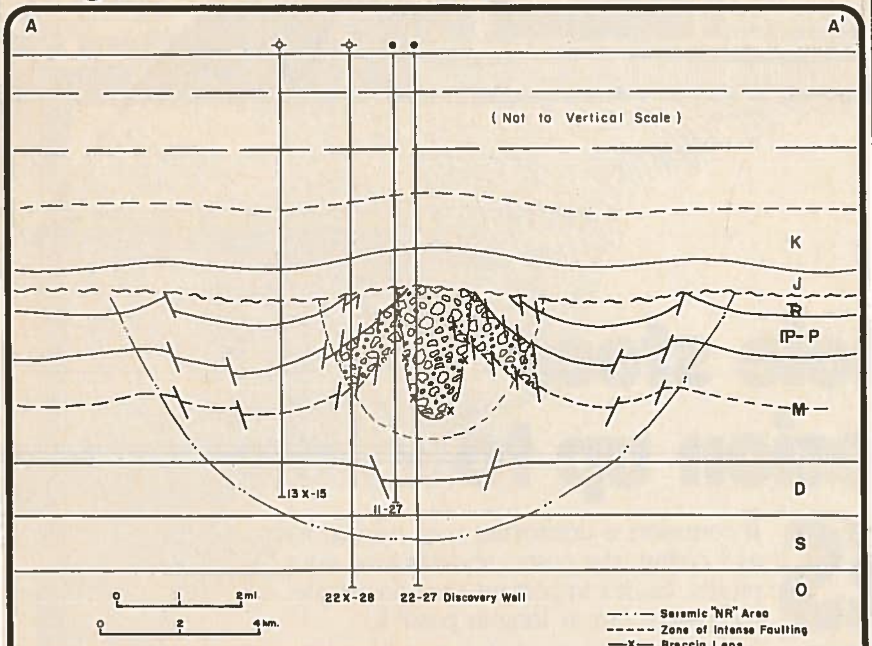
Newporte. Viewfield and Red Wing Creek structures both exhibit moderate erosional profiles developed in sedimentary rocks.

An example of a similar erosional profile developed in crystalline rocks and buried by a marine transgression is Newporte. The Newporte structure (Des-Lacs field) in Renville County, North Dakota, most likely originated by hypervelocity impact, and could represent the first discovery of a petroliferous basement astrobleme. A conceptual cross-section of the 3.2 km diameter circular depressed structure is shown in (Fig. 8).

Geophysical evidence indicated that the structural feature involved all early Paleozoic sediments and probably the Precambrian basement as well. The 23X-9 Larson wildcat was subsequently drilled to basement with primary objectives in the Ordovician.

Fig 7

Diagrammatic cross-section*



*OF Red Wing Creek (modified from Brenan et al. 1975)

No encouraging recoveries of oil were found in this interval, but the Cambro-Ordovician Deadwood sandstones, resting unconformably upon Precambrian schist, flowed 233 bbl of 30° gravity crude at an estimated rate of 166 bbl/hr. The well was drilled about 130 ft into basement with no more hydrocarbon shows.

Another well, 14-34 Mott, positioned on the other side of the structure, penetrated a "highly fractured, vuggy, and weathered Precambrian gneiss-schist sequence" nearly 350 ft structurally high to Precambrian rocks in the 23X-9 Larson well. The Mott well was cored and drill-stem tested a flow of 202 bo/d during an open period of 190 min. It was later completed pumping 40 bbl oil, 380 bw/d, and 10 Mcfd.

Core analysis of the Precambrian interval 9,094-99 ft shows an average porosity of 4.7% and an average permeability of 0.48 md. Fluid production rates are incompatible with the low matrix values indicating that some of the fractures are open and interconnecting. At present, no wells have penetrated areas in the structure where shock metamorphic features (if present) would be found. Newporte is therefore classified as a possible impact crater.

Recognition problems. On the basis of probability, considering terrestrial cratering rates and the 3.3 million wells drilled into the earth's crust, it is with certainty that unrecognized impact features have been encountered and that many of these contain commercial hydrocarbons.

Undoubtedly many explorationists have unknowingly penetrated impact features and, not finding commercial hydrocarbons on the first or second try, have given up only to have another operator move in and make the discovery.

If the petroleum geologist encounters and is unable to recognize the structural changes or shock metamorphic effects resulting from an impact event, he cannot realize that the well is into a structure which is independent of the regional geology and possesses a unique geometry of its own.

Housed within that unique geometry are potential pay zones of magnitudes which tend to dwarf classical geological features. These potential pay zones are present not only in structural traps, but stratigraphic traps as well—the most unusual resulting from the syncline profile of the breccia lens itself.

The basement syndrome. It is the overwhelming opinion of explorationists that basement rock is essentially "nonproductive."

Calculations show that crystalline basement currently supplies less than 1% of total world oil production, which would appear to justify stopping the drill bit short of entering it. Such justification, however, is based on totally inadequate statistical information, and represents poor geologic reasoning. The explanation for the "nonproductive" reputation of basement may not lie in the nature of the rock, but results from the routine practice of not drilling into it.

In a study of more than 107,000 wells drilled in eight U.S. petroleum basins, less than 0.45% penetrated basement. The "basement syndrome" continues to dominate exploratory drilling regardless of the basement depth. Many pronounced and subtle basement syncline features on seismic are indicative of impact craters but are unconsciously eliminated from consideration. These potential multibillion barrel reservoirs continue to be overlooked.

Detection methods. Processed seismic section models can reveal the expected signals from subsurface astroblemes at various erosional levels, overlain by differing sedimentary sequences, while gravity analysis can show the differences in rock density resulting from impact events.

Hypervelocity impact in certain types of crystalline basement rock can produce unusual magnetic properties best explained by Enchanced Natural Remnant Magnetism and/or Shock Induced Polarization.

Similar anomalies have been noted in particular tektites, impactites, and lunar rocks.

Implications of inorganic hydrocarbons to basement astroblemes. Some geologists and astrophysicists have proposed that the earth's hydrocarbon resources are the result of both organic and inorganic (abiogenic) activity, the latter from some as yet inadequately explained process occurring in the earth's upper mantle. If by some remote possibility this is correct, then the presence of astroblemes in basement rock has important implications.

Such impact scars could be the first reservoirs these rising abiogenic hydrocarbons would encounter and could contain enormous reserves if properly sealed by overlying sediments.

Conclusions. The cratering process is fundamental to all the planetary bodies so far examined and was one of the dominant forces which sculptured the earth's pretransgressive basement configuration.

This exogenic mechanism, in conjunction with normal terrestrial processes, assures the presence of many areas of fractured and brecciated crystalline rock which are conducive to hydrocarbon accumulations. An unknown number of astroblemes have been buried at various stages of erosion some of which, possibly like Newporte, were in the right place at the right time. Had an even larger magnitude impact occurred at this location, petroleum accumulations of hundreds of millions of barrels could have resulted.

Geologists should become familiar with shock metamorphic effects and be aware of the structural parameters associated with astroblemes. Suspicious gravity, seismic, and magnetic anomalies in basement should be penetrated and tested where drilling depth permits.

These anomalies include elevated areas of basement as well as synclines, especially in basins having overpressured conditions.

Structural and reservoir considerations should take precedence over classical source rock arguments, and the possibility of unconventional hydrocarbon generation should be left open. This includes abiogenic synthesis as well as recycled kerogen, which eliminates the necessity of primary migration from fine grained carrier beds.

Both of these proposals run contrary to our basic concepts in petroleum geology.

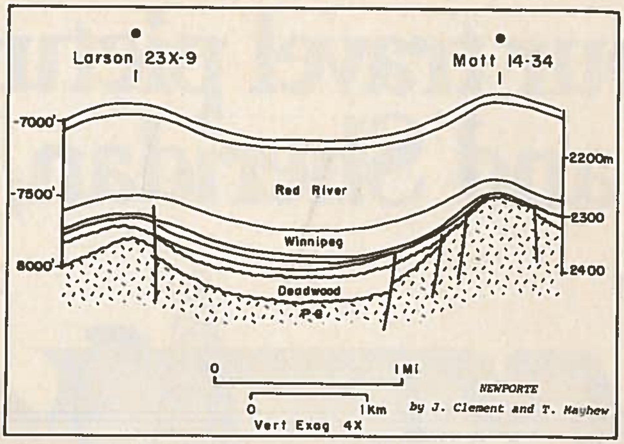
Detection of astroblemes by geophysical or geological methods means that fractured reservoirs have been located.

In basement rock, these features represent the closest known potential reservoirs to proposed upper mantle abiogenic activity.

The implications that these reservoirs could accumulate abiogenic hydrocarbons from the base of the structure upwards are profound and need to be tested. ▪

Fig. 8

Conceptual cross-section*



*Newporte field (from Clement and Mayhew 1979).

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This is a condensed version of a paper presented in Journal of Petroleum Geology, 3,3, pp. 279-302, 1981. Author is Richard R. Donofrio, exploration and production department, American Ultramar Ltd., Mt. Kisco, N.Y. For references and a detailed discussion of impact craters, readers should consult the unabridged paper. This condensation is published also through the courtesy of the Petroleum Exploration Society of New York.

OKLAHOMA

Deep will be a wildcat in southwestern Grady County in southwestern Oklahoma.

Magic Circle Energy Co. will drill to 20,000 ft to the Goddard at 1 Anna Maude in SE SE SE NW 18-3n-8w, 3 miles north of production in the Marlow district. This test is near a newly staked wildcat made by Kerr-McGee in Comanche County. The Kermac well is 1 Ford in 19-3n8w. It will test to the Boatwright section of the Springer at 22,000 ft. Several other tests were located in 3n-9w, Comanche County, by the Oklahoma City firm.

Custer County. An-Son Corp. has a new Atoka sand field at 1-10 White in C NE 10-13n-20w.

Flow was 1,250 Mcfd and 25 bc/d, 53°, on a 20/64 in. choke. Pay is from perforations at 13,808-896 ft. Tubing pressure was 1,000 psi. The well is 3½ miles northeast of Southeast Hammon Morrow field.

Also in Custer County, Seneca Oil Co. extended the northwest side of Southeast Crane field.

The 1-36 Combs in 36-16n-15w flowed 2,100 Mcfd from the Morrow at 10,868-882 ft and 26 bc/d, 46°, on an 8/64 in. choke.

Creek County. Schonfield Oil & Gas Co. 1 Harding in NE NE SE 36-14n-9e, Tuskegee field, Creek County, flowed 400 bo/d, 37°, on a ½ in. choke from Dutcher sand through perforations at 2,903-10 ft.

Caddo County. Phillips Petroleum Co. has a Marchand sand well at 44-2 East Binger unit in SW NE SW NW 36-10n-11w, Binger field.

New well flowed 1,300 bo/d and 760 Mcfd on a 16/64 in. choke from perforations at 9,946-10,015 ft. Casing pressure was 950 psi. More tests are due at this well.

LeFlore County. Spiro pay is reported at a well in Kinta field.

Sabine Production Co. 1-36 Gamble in C SW 36-10n-24e flowed 965 Mcfd on a 13/64 in. choke from perforations at 5,484-5,555 ft.

Calculated open flow was 2,816 Mcfd with shutin tubing pressure 855 psi. Shutin bottomhole pressure was 1,010 psi.

Carter County. In southern Oklahoma, Jones & Pellow completed a Sycamore well at 11-1 Boyd in C SW SW 11-1s-3w.

The well flowed 285 bo/d, 40°, and 525 Mcfd on a 22/64 in. choke with tubing pressure 500 psi. Location is in giant Sho-Vel-Tum field.

Oklahoma oil and gas activity continues to grow with action in every producing county in the state.

Keith F. Walker has a good Ordovician Viola oil well at 2 Carlile in NE NE SW 36-6s-2w, Love County. The southern Oklahoma well flowed 649 bo/d, 43°, from Viola at 8,445-8,764 ft. Tubing pressure was 130 psi on a ¾ in. choke. Gas flow was 565 Mcfd. Location is in North Pike field.

Roger Mills County. In western Oklahoma, Tenneco Oil Co. completed 1-19 Allen in C SE 19-13n-21w, Southwest Hammon field.

Flow was 3,829 Mcfd and 1 bbl of oil from the Red Fork pay through perforations at 13,022-13,332 ft on an 11/64 in. choke. Tubing pressure was 4,500 psi.

PCX Corp. 1 Walker in 24-13n-22w, Southeast Strong City field, flowed 3,000 Mcfd on a 16/64 in. choke from Des Moines pay at 12,942-13,406 ft. Tubing pressure was 2,200 psi.

Natomas North America completed 2 Simmons in 17-12n-22w, West Carpenter field, flowing 1,900 Mcfd from perforations at 14,490-14,526 ft in the Atoka. Tubing pressure was 4,200 psi.

Creek County. A large gas well is reported in West Kellyville District.

Bristow Resources completed 3 Elias-Pauline in NE NW NW 36-17n-9e. Flow was 3,000 Mcfd and 50 bo/d, 38°, from perforations in the Red Fork sand at 2,272-80 ft.