The structural closures in the sediments above the reefs account for another type of trap for oil and gas. The Devonian Nisku and Wabamun carbonates, the Cretaceous Basal Quartz and Viking sandstones, and in several places the Cretaceous Cardium sandstone contain oil and gas accumulations with geometry of fluid segregations similar to that found in anticlinal closures. It must be pointed out, however, that in many places, porosity-permeability conditions in these reservoirs modify the geometry of the fluid accumulations to a great degree.

A third type of trap results from erratic porosity development related to the effect of buried highs on subsequent sedimentation. In several places improved porosity conditions in the Devonian Nisku formation account for the extension of oil accumulation some distance beyond the structural closures above the reef massifs. The development of thicker, more porous sands can be found in the Cretaceous Basal Quartz above the inter-reef channels. Some old topographic depressions in the unconformity surface between the Paleozoics and Cretaceous are filled with porous sand lenses in the Basal Quartz sequence.

A fourth type of trap is found in the truncated edge of several Mississippian units. Accumulations of oil and gas are found in porous Rundle carbonates as their regional updip termination crosses the Edmonton reef chain.

ROLAND F. HERBST, Lawrence Radiation Laboratory, University of California, Livermore, California

Application of Nuclear Explosives in Exploitation of Underground Resources

The Rainier detonation of 1957 and the underground detonations of October, 1958, produced phenomena of heat, fracturing, and melting which have possible application to mineral and petroleum production. Such effects may be particularly applicable to oil sands and oil shales.

G. W. HURLEY, Pan American Petroleum Corporation, Casper, Wyoming

Overthrust Faulting and Paleozoic Gas Prospects in Montana's Disturbed Belt

The Disturbed belt of Montana lies on the hinge-line between the Central Stable platform on the east and the Rocky Mountain geosyncline on the west. It lies west of the Sweetgrass arch and includes the Rocky Mountain front ranges of western Montana. The Disturbed belt is characterized by a zone of overthrust faulting and folding extending from the Missouri River northward into Canada. Some of the largest gas and distillate reserves in North America have been found in one or more thrust sheets of Mississippian rocks in Canada at Pincher Creek and Waterton Lake and a recent gas discovery was completed in the Devonian formation at Castle River. Northern Natural Gas Company's recent Mississippian gas discovery in Sec. 13, T. 26 N., R. 8 W., may be the first evidence that such accumulations are also present in Montana's Disturbed belt.

Unconformities between the Cambrian and Devonian and between the Mississippian and Jurassic are evidence that the area was tectonically active during Paleozoic time and isopachs of the Jurassic and Cretaceous formations indicate that this activity continued intermittently throughout Mesozoic time. The characteristic overthrust faulting from the west is the result of the Laramide orogeny of early Tertiary time.

The structure of Montana's Disturbed belt is divisible into three layers each younger in age: (1) a regional layer of relatively undeformed rocks comprising the west flank of the Sweetgrass arch over which the high-angle thrust layer has ridden; (2) a high-angle thrust layer of complex faulting and drag folds typical of the Disturbed belt structures; and (3) a low-angle thrust layer, commonly known as the Lewis overthrust, which overrode the high-angle thrust layer. Subsequent high-angle block faulting has added further complexity to the structures.

Three types of traps similar to those of the Canadian Disturbed belt are present: (1) fault traps on the wedge-edge of the Paleozoic thrust sheets; (2) drag folds formed as the result of thrusting; and (3) folds occurring west of the zone of drag folding as typified at Savannah Creek in Alberta. The Northern Natural Gas Company's Mississippian discovery at Blackleaf Creek is of the wedge-edge type.

Structural interpretation of this area is difficult and drilling costs are high. Therefore, much money will have to be spent before the economic possibilities of the hydrocarbons in Montana's Disturbed belt have been adequately evaluated.

VINCENT C. KELLEY, University of New Mexico, Albuquerque, New Mexico

Fractures in Sedimentary Rocks

The most abundant kind of deformation of rocks is by fracturing. There are three principal classes of fractures—(1) joints, (2) faults, and (3) small, irregular breaks (including shatter and breccia zones). In general, joints may be defined as more or less regular groups of relatively long fractures that are paralleled by little or no displacement or orientation of rock components.

Joints occur in sets that may be parallel, radiate, or concentric. Sets occur singly or severally and with no universality of systems. The angular relations of intersecting sets range from sharply acute to normal. In a given area two or three sets may be about equally developed in length and frequency, or one set may predominate. Joint sets may be confined to single beds or transect several formations and extend for more than a hundred miles. Strong and possibly thick beds tend to be less jointed, but existing joints are relatively long. Thin, relatively brittle beds are almost always jointed normal to their bedding. Relatively weak rocks are generally disrupted by small, irregular breaks.

Shale, mudstone, claystone, and siltstone probably are much more fractured than any other sedimentary type, but the breaks are generally tight, inconsistently oriented, short, irregular, and commonly oblique to the bedding. Although individual joints are comparatively short in shale or claystone they are probably concentrated into zones which may have marked vertical or horizontal extent. The most persistent and apparent jointing in regions of flat beds is nearly vertical.

Very many if not most joints appear to have formed soon after deposition during compaction, irregular settling, and broad, although irregular downwarping of the area of accumulation. Such early formed joints may be local and irregular, or they may be widely developed and display certain marked trends because of secular deep-seated wrenching, to broad coupling stresses acting mildly upon the entire area of deposition, or because of persistent depositional lineations. Composition, degree of consolidation, and bed-to-bed variation in brittleness or ductility strongly affect the amount of early fracturing. Early formed joints as well as some late ones have been thought to be caused by earthquakes and earth tides, but wind and glacial movement may more easily joint some types of near-surface rocks.

Despite the evidence of early jointing during little or no deformation, undoubtedly new jointing develops during moderate and strong crustal deformation. During this operation early formed joints may be extended and the angular relations between sets may be changed.

Under dynamic compression the stress pattern becomes more intricate, refracted, and variable. The local stress patterns change repeatedly with the progression of the deformation and the development of principal flexes and shear zones. Fracture thresholds are reached at various times and places for the various rock components, and withal the fracture pattern in its culmination is likely to be a complex mixture of reoriented non-diastrophic and multiple-stage tectonic joints, some of small and some of great dimensions. In general, however, the fracturing is accentuated in the parts that are otherwise most deformed and in the beds least supported by adjoining incompetent members. Fracture systems of uplifts and fold belts commonly have such a complex derivation that they bear little obvious or regular relation to them.

Fracture reservoirs for petroleum result where relatively brittle rocks are broken in an irregular manner and on a scale and frequency that may develop in a network in otherwise effectively impervious rocks. Sandstone, for example, may have many large fractures, but interconnection and imperviousness are not generally great. Shale or claystones may contain many fractures, but they are usually tight, short, and not so effectively connected. Fracture reservoirs may occur in any common lithologic type with the possible exception of salt. The requisites for effective development of fractured reservoirs in claystone or impervious siltstone appear to be (1) increased brittleness with respect to adjacent similar beds and (2) proximity of source petroleum. Shatter and breccia zones of several origins may also serve as tabular reservoirs or channels between reservoirs. These form principally in association with faulting or with folding where brittle beds are in maximum stress imbalance or reach a threshold of fracturing.

WILLIAM V. KNIGHT and HARRELL BUDD, Petro-Atlas Inc., and consultant, Farmington, New Mexico

Horseshoe-Gallup Field—Preliminary Report

The Horseshoe Canyon-Gallup field, T. 30–31 N., R. 16–17 W., San Juan County, New Mexico, was discovered in September, 1956. It now contains approximately 90 wells.

The field produces from the Gallup formation of the Mesaverde group. The oil accumulations are stratigraphic and occur in highly localized sandstone lenses. The thickness of these lenses ranges from a feather-edge to more than 20 feet. Although numerous lenses are present, they are usually referred to as belonging to one of the two "sands." The "upper sand," which consists of several interbedded sandstones and shales, is the most widespread. It produces throughout the field. The "lower sand" is long and narrow. It generally consists of not more than two main sand bodies with thin lenses, in places found above and below. It is found throughout the northwest-southeast extent of the field.

Structural information to date is adequate to indicate that it bears only a minor relation to accumulation.

Shallow depths and substantial reserves make this field possibly the best oil investment in the Four Corners area. Average depth is 1,400 feet with over-all cost of approximately $20 per foot for a completed well.

Producible oil reserves per well vary due to the lenticular nature of the reservoirs; however, 3,000 barrels per acre is average. Pay-out period is approximately 7 months with a 4:1 ratio of investment to return.

Future exploration for this stratigraphic type of Gallup accumulation should be limited to the