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 band of deposition between the area of continuous beach sands and the seaward pinch-out of the Gallup tongue. In addition, fractured reservoirs with poorly developed sands could be expected throughout this band and for a short distance seaward.

WILLIAM WYMAN MALLORY, Ball Associates, Denver, Colorado

Rocky Mountain Association of Geologists Symposium on Pennsylvanian Rocks of Colorado

The Rocky Mountain Association of Geologists, Denver, Colorado, published in 1958 a volume with the above title in conjunction with its field conference on Pennsylvanian rocks of the Maroon basin.

The principal results of these collected studies show that Pennsylvanian tectonism was dominated by vigorous growth of northwest-trending mountain ranges (Frontrangia and Uncompahgria) and their attendant depositional troughs. These obliterated the amoeboid patterns of gentle epeirogeny in Colorado established during early and middle Paleozoic time. Pennsylvanian depositional history began in Colorado with the accumulation of a red clay regolith, the Molas formation, upon the maturely dissected Mississippian Leadville limestone. Four Pennsylvanian depositional basins (or troughs), the Denver, Maroon, Paradox, and Raton, between and adjacent to Uncompahgria and Frontrangia, contain abundant thicknesses of all lithologic types common to cratonic sediments. Two of the basins in western Colorado, the Maroon and Paradox, exhibit extensive evaporites, the Paradox and Eagle sequences. All the basins contain large volumes of red, arkosic conglomerates and finer clastics (the Fountain, Maroon, Cutler and Sangre de Cristo formations) which grade laterally into marine limestones, shales and sandstones with or without passing through an evaporite facies.

Western Colorado marine sequences bear the names Hermosa group, Morgan formation and Weber sandstone. In the Raton basin the Sangre de Cristo and the Magdalena group, predominantly clastic, comprise the section. In the Denver basin, only the Fountain arkose facies outcrops (except for a trace of Glen Eyrie claystone near Colorado Springs); the series terms Morrow, Atoka, Des Moines, Missouri, and Virgil have been borrowed from the Mid-Continent region as faunal subdivisions.

The uplifts attained maximum development in the Des Moines epoch and continued tectonically active into middle Permian or Leonard time. Pennsylvanian deposition carried over without hiatus into the Wolfcamp epoch of the Permian period. The rejuvenated Uncompahgre and the Front range uplifts (now masked by the Laramide Front and Park Ranges) are part of the present tectonic pattern of Colorado.

The bulk of Colorado oil may be classified as follows: (1) Cretaceous sandstone lenses scattered across the Denver basin, (2) the Weber sandstone of the Rangely pool in the Maroon basin, (3) the Hermosa carbonate reservoirs in the Paradox basin. The last two, Permo-Pennsylvanian in age, contain outstandingly important additional reserves. The size and relative youth of Pennsylvanian carbonate pools indicate that additional large reserves can be anticipated in these rocks.

R. G. MCCROSSAN, Imperial Oil Limited, Calgary, Alberta

Application of Resistivity Mapping to Upper Devonian Interreef Ireton Formation of Alberta

The Woodbend group of Upper Devonian age in central Alberta is a reef complex characterized by large-scale facies changes. The reefs, which grew in a subsiding basin and were initiated in restricted areas of suitable depth, are surrounded by the calcareous shales and argillaceous limestones of the Duvernay and Ireton formations. Isopach maps indicate relative movements of the basin during deposition. Very fine carbonate clastics derived from the reefs were spread throughout the basin during Duvernay and lower Ireton time. The distribution of these carbonates was detected by mapping the average apparent resistivity of a stratigraphic interval from borehole measurements.

The pore volume of these rocks decreases with increasing depth and carbonate content, and resistivity increases correspondingly. The straight-line relation of carbonate content and porosity suggests that reduction of porosity is directly proportional to the volume of calcite grains present. Other factors affecting porosity aside from carbonate content and depth of burial are small by comparison. Internal redeposition of calcium carbonate has been unimportant.

Resistivity mapping in the subsurface shows promise of being a useful exploration tool for determining the relative amount of coarser grains in shale.

RICHARD M. MODEL and JOHN J. SCHULTE, Northern Pacific Railway Company, Oil Development Department, Billings, Montana

Oil and Gas Possibilities of Porcupine Dome, Rosebud County, Montana

"What is the matter with Porcupine dome?" This question is often asked by explorationists working in central Montana. Although it does not have as much closure as some central Montana structures, in areal extent it is the largest feature in the Big Snowy anticlinorium. Twenty wells drilled