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PRELIMINARY DIGITAL STRUCTURE MAPS FOR THE TOP OF THE MADISON GROUP AND THE SWIFT, FALL RIVER, MOWRY, AND JUDITH RIVER FORMATIONS, CENTRAL AND EASTERN MONTANA

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INTRODUCTION

The MBMG is in the early stages of developing digital subsurface geologic maps for use in computer applications such as ESRI ArcPro, and eventually for the construction of a statewide 3D geological model. A digital subsurface structure grid of the top of the Eagle Formation has been produced for central and eastern Montana (Gunderson, 2020). A digital model of the top of Precambrian basement establishes a basal surface for MBMG's 3D geologic model (Gunderson, 2024).

Five additional stratigraphic horizons were mapped across central and eastern Montana using formation top elevations interpreted from oil and gas wells, along with previously published structure maps and cross-sections (see References); the results are presented here. The five horizons are the tops of the Mississippian Madison Group, the Jurassic Swift Formation, and the Cretaceous Fall River, Mowry, and Judith River Formations. These formations are laterally extensive and serve as important aquifers, petroleum reservoirs, or both. The Fall River Formation and, to a lesser extent, the Swift Formation are also used for waste water disposal. These digital surfaces and structure contour maps help to further define the framework architecture for a 3D geologic model of Montana.

DATA AND METHODS

Wireline logs, acquired in wellbores after drilling, provide critical data for delineating and mapping subsurface formations. In a study of Montana's aquifers, Feltis and others (1981) provided valuable data for Jurassic, Cretaceous, and Tertiary formation depths for over 2,000 petroleum exploration wells scattered across Montana's plains. These data were the basis for several hand-contoured structure and thickness maps covering central and eastern Montana, including structural interpretations for the top of the Judith River Formation (Feltis, 1982a; Noble and others, 1982a; Bergantino, 2012a–d, 2013, 2014, 2019a–f), Fall River Formation (Feltis, 1982b), and Swift Formation (Feltis, 1982c; Noble and others, 1982b,c; Bergantino, 2019g). Structure maps for the top of the Madison Group were published by Feltis (1980a–d, 1981a–g, 1983, 1984a–d, 1985a,b), Noble and others (1982d,e), and Bergantino (1985). The structural interpretations of these authors are broadly similar but can differ significantly in places. Additional formation tops data and reinterpretation could help resolve some of these discrepancies and refine the structural surfaces. Although these formations can occur in intermontane basins of western Montana (west of the Rocky Mountain Front and the Beartooth Mountains), no attempt was made to map this part of the State due to the structural complexity and dearth of subsurface data in these basins and surrounding mountains.

Well header and location data were acquired from the Montana Board of Oil and Gas. Raster images of geophysical logs were obtained from MJ Systems of Calgary, Alberta. All data were loaded into S&P Global's PETRA software for interpretation. Formation top depths were interpreted from wellbore geophysical logs and lithologic descriptions. Formation elevations were gridded using PETRA's "Least Squares Method" interpolation algorithm with a 2,000 or 3,000 m square grid spacing, depending on data distribution.

The Judith River, Mowry, Fall River, and Swift structure surfaces were created by gridding formation top elevations taken from the well data published by Feltis and others (1981), combined with our stratigraphic picks from hundreds of additional oil and gas wells. Well header data and formation top elevations were also obtained for wells located in neighboring states and provinces to minimize boundary effects along Montana's state border. Hand-drawn contours based on our interpretations were used locally to guide the gridding process. We used isochore maps to help maintain reasonable consistency in the shape of surfaces near structures, such as folds and faults, particularly where well control was limited.

In contrast to the other four surfaces, the Madison Group structure surface was constructed by digitizing and gridding the contour lines from Feltis (1980a–d, 1981a–g, 1983, 1984a–d, 1985a–b), without additional well data. Feltis' structure contours are drawn on a 1° x 2° quadrangle basis, with sufficient detail for creating a preliminary digital surface for the top of the Madison Group.

Grids were imported into ESRI ArcPro, where raster elevation surfaces were generated with a 500 m cell size. The raster surfaces, grids, and contour lines were clipped using hand-drawn boundaries that approximate the outcrop extent of each formation (Vuke and others, 2007).

RESULTS

The results of this project are digital structure grids, raster surfaces, and corresponding structure contours showing the topography of five surfaces: the top of the Madison Group and the tops of the Swift, Fall River, Mowry, and Judith River Formations in central and eastern Montana (plates 1–5). These data and results are compiled in an ESRI ArcPro map package (MT_regional_structure.mpkx). The coordinate reference system for the elements contained in the map package is NAD83 State Plane Montana FIPS 2500 (m).

For each of the five mapped surfaces, the geodatabase within the map package contains:

- Well header information and the formation elevations used for gridding,
- Raw and clipped elevation grids (2,000 m or 3,000 m square spacing),
- A raster surface representing structural elevation (in ft), created with a 500 m cell size,
- Two sets of structure contour lines, drawn at both 200-ft and 500-ft contour intervals, and
- A boundary polygon approximating outcrop extent.

For portability to other software applications, Excel data files are provided for the final, clipped structure grids (structure_grid_excel_files.zip). The structure grids are in XYZ format, where X represents longitude, Y represents latitude, and Z represents the elevation at the top of the formation in feet. An Excel data file containing well data points is also provided (well_data_points.xlsx).

There is high confidence in the accuracy of the raster surface and contour lines in major sedimentary basins and in the plains that lie between the basins. In these regions, formations are relatively flat-lying or gently dipping, and there are sufficient well data to generate an accurate surface. The accuracy is less certain along the structurally complex Central Montana Uplift and near some of the other major uplifts where well data are sparse and beds are steeply dipping. Nevertheless, these preliminary digital surfaces are useful approximations for subsurface structure; they can be easily used in computer applications for visualization and grid-to-grid manipulations.

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