Geomorphic and structural features of the Alliance 1° × 2° Quadrangle, western Nebraska, discernible from synthetic-aperture radar imagery and digital shaded-relief maps

R. F. DIFFENDAL, JR. *Conservation and Survey Division, IANR, University of Nebraska-Lincoln, Lincoln, Nebraska 68588-0517*

ABSTRACT

The digital shaded-relief map of the United States and the synthetic-aperture radar map of the Alliance Nebraska 1° × 2° area prepared by the U.S. Geological Survey (USGS) in the former case and for the USGS in the latter show oriented landforms and lineaments in northwest Nebraska. Parallel and subparallel hills and valleys developed on different geologic materials ranging from shales through sandstones to loess and eolian sand appear to be wind erosional features subsequently modified by running water. The long axes of these hills and valleys generally trend between N40°W and N50°W. Similar features also occur across major areas of the Great Plains from Montana southeast at least to Kansas. Most of the lineaments are in two sets, one trending northeast, the other northwest. There are some east-west and north-south trending lineaments in the western part of the quadrangle, some circular features in the northwest, and some chevronlike lineaments in the north-central part. Some lineaments appear to coincide wholly or in part with known faults in western Nebraska or with extensions of faults in east-central Wyoming into northwest Nebraska. All other lineaments are probably reflections of either jointing or, more likely, of faulting. Additional field work will be needed to verify which of these two, if either, is responsible for any particular lineament.

INTRODUCTION

In 1988 the U.S. Geological Survey (USGS) published a radar image mosaic of the area covered on the Alliance, Nebraska, 1° × 2° topographic map at the scale of 1:250,000. Then in 1991 the USGS published a digital shaded-relief map of the 48 contiguous states at a scale of 1:1,000,000. Both of these maps depict numerous linear features in northwest Nebraska and the shaded relief map seems to indicate that some continue into adjacent states. The features seem to fall into two groups, those that are formed to a greater extent by eolian and/or fluvial processes and those that are structurally formed. The purposes of this paper are to review reports and data about geomorphology and structural geology in northwestern Nebraska and adjacent areas, to compare these data to data on the groups of features discernible on the two maps, and to suggest which groups are probably largely due to geomorphic processes and which are formed primarily by structural processes.

STUDY AREA

The study area is in northwestern Nebraska (Fig. 1) and lies between 42° and 43° North Latitude and between 102° and 104° West Longitude. Parts of five physiographic regions and two principal rivers occur in the study area. The physiographic regions are the Pierre Hills, Pine Ridge, Box Butte Tableland, Sand Hills, and the North Platte Valley (Fig. 2). The Niobrara River, the White River, and their tributaries drain much of the northern part of the study area, while tributaries to the North Platte River (itself not in the study area) drain the southwest. Drainages on much of the Box Butte Tableland stop abruptly in the east at the boundary with the Sand Hills.

The Pierre Hills occupy the northwestern part of the map area and are generally underlain by the Pierre Shale of Cretaceous age. Some areas of so-called "badlands" Tertiary beds of the Brule and Chadron formations, White River Group, overlie the Pierre in places, while some Cretaceous strata older than the Pierre crop out in the Chadron Dome area northeast of Chadron, Nebraska (Moore, 1954; Swinehart et al., 1985; Burchett, 1986). Fill terraces composed of Quaternary deposits occur adjacent to floodplains of the White River and its tributaries, and on some hilltops where inverted topography marks the position of the deepest parts of old valley fills.

The Pine Ridge forms a prominent north-facing escarpment up to about 1000 ft (305 m) higher than the Pierre Hills and is underlain directly by Tertiary strata of the Ogallala, Arikaree, and White River groups and beneath these by the Cretaceous units exposed in the Pierre Hills. The Arikaree and older rocks on the north slope of the Pine Ridge are faulted and generally dip southward, both indications that the Pine Ridge is part of the area of deformation of the Black Hills (Swinehart, et al., 1985). The divide between the north and south slopes of the Pine Ridge (dashed line in Fig. 2) separates the generally narrower and more steeply sloping north part which is drained by tributaries of the White River from the more gently sloping south part drained by Niobrara River tributaries.

The Box Butte Tableland (Fig. 2) is underlain by Ogallala and older strata (Yatkola, 1978; Swinehart, et al., 1985). Its surface, an extension of the High Plains of Wyoming into Nebraska, is much flatter than the Pine Ridge and is up to 200 ft (61 m) lower than the highest parts of the Pine Ridge to the north. The Tertiary formations beneath the tableland occur as valley fills cut in places by faults, particularly near the Niobrara Valley.

The Sand Hills is part of the large Nebraska Sand Hills Physiographic Province which covers some 20,000 square miles (51,800 square kilometers) of west-central Nebraska (Swinehart, 1990). The surface of this region, mostly in the eastern part of the study area, is underlain by eolian sand which was formed into various types of dunes in the Holocene (Swinehart, 1990). Swinehart (1990) subdivided the dune field on the basis of differences in dune morphology which can be seen without difficulty on radar images (Figs. 1 and 2). The eolian sand, up to 300 ft (91 m) thick, covers parts of the Box Butte Tableland on the east, south, and west, as well as small parts of the eastern Pine Ridge (Fig. 2).

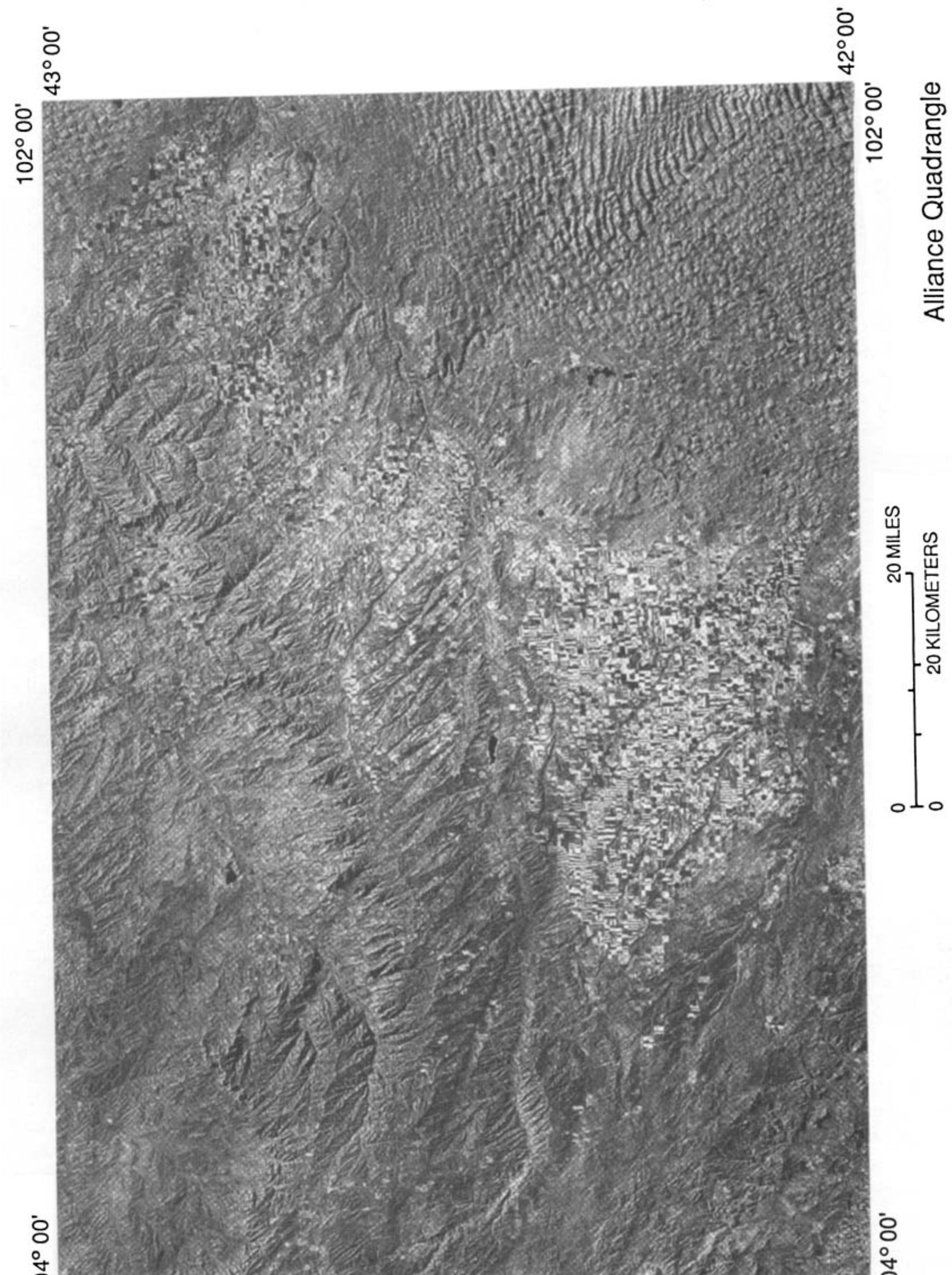

Figure 1. Synthetic-aperture radar image of the Alliance, Nebraska; South Dakota Quadrangle (Anonymous, U.S. Geological Survey, 1988).

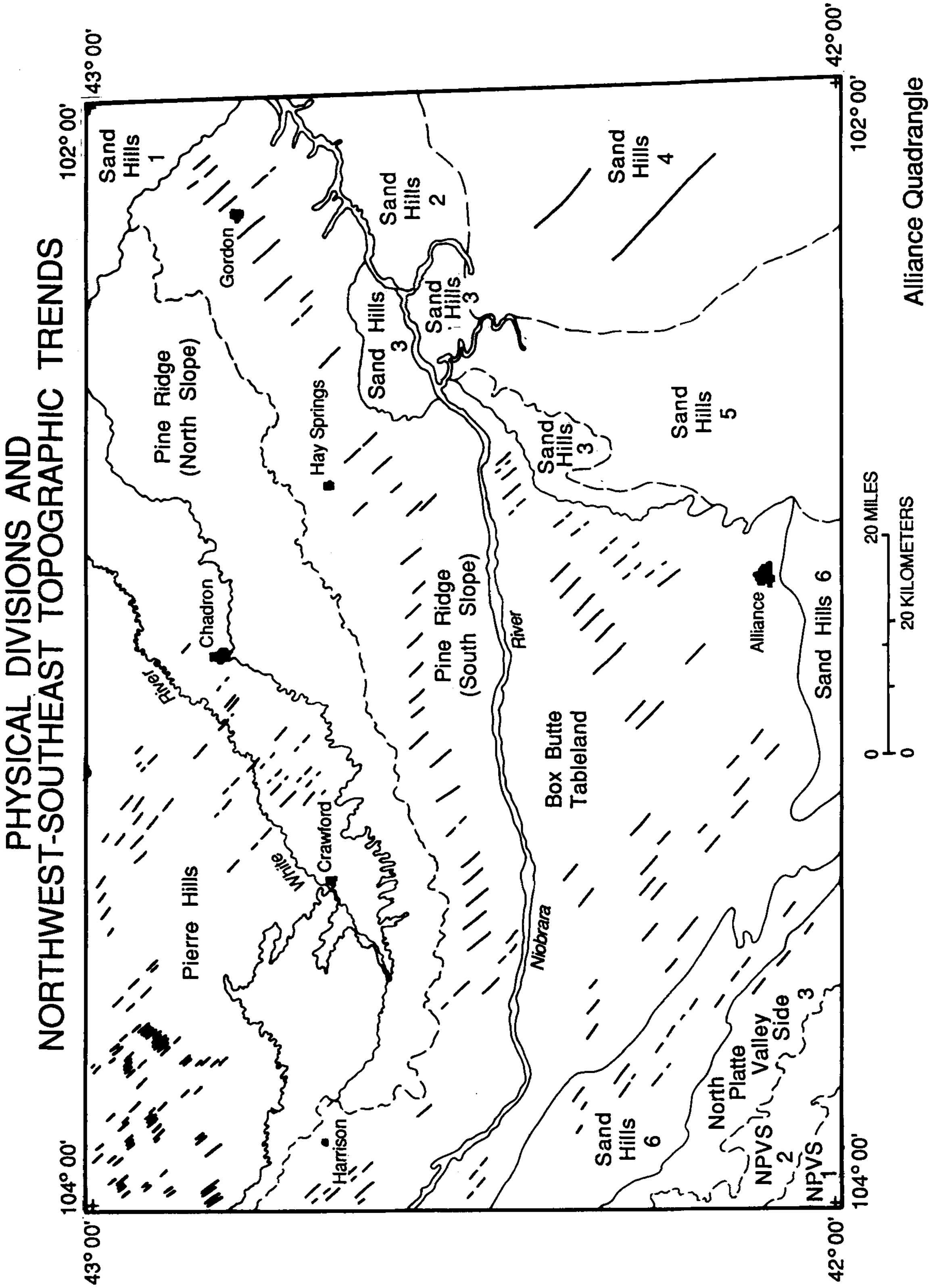

Figure 2. Physical divisions and northwest-southeast topographic trends, Alliance Quadrangle. Compare trends with Fig. 1. Numbered subdivisions of the Sand Hills and the North Platte Valley Side are physiographic subdivisions based on changes in dune type and on slope and surface configuration changes, respectively.

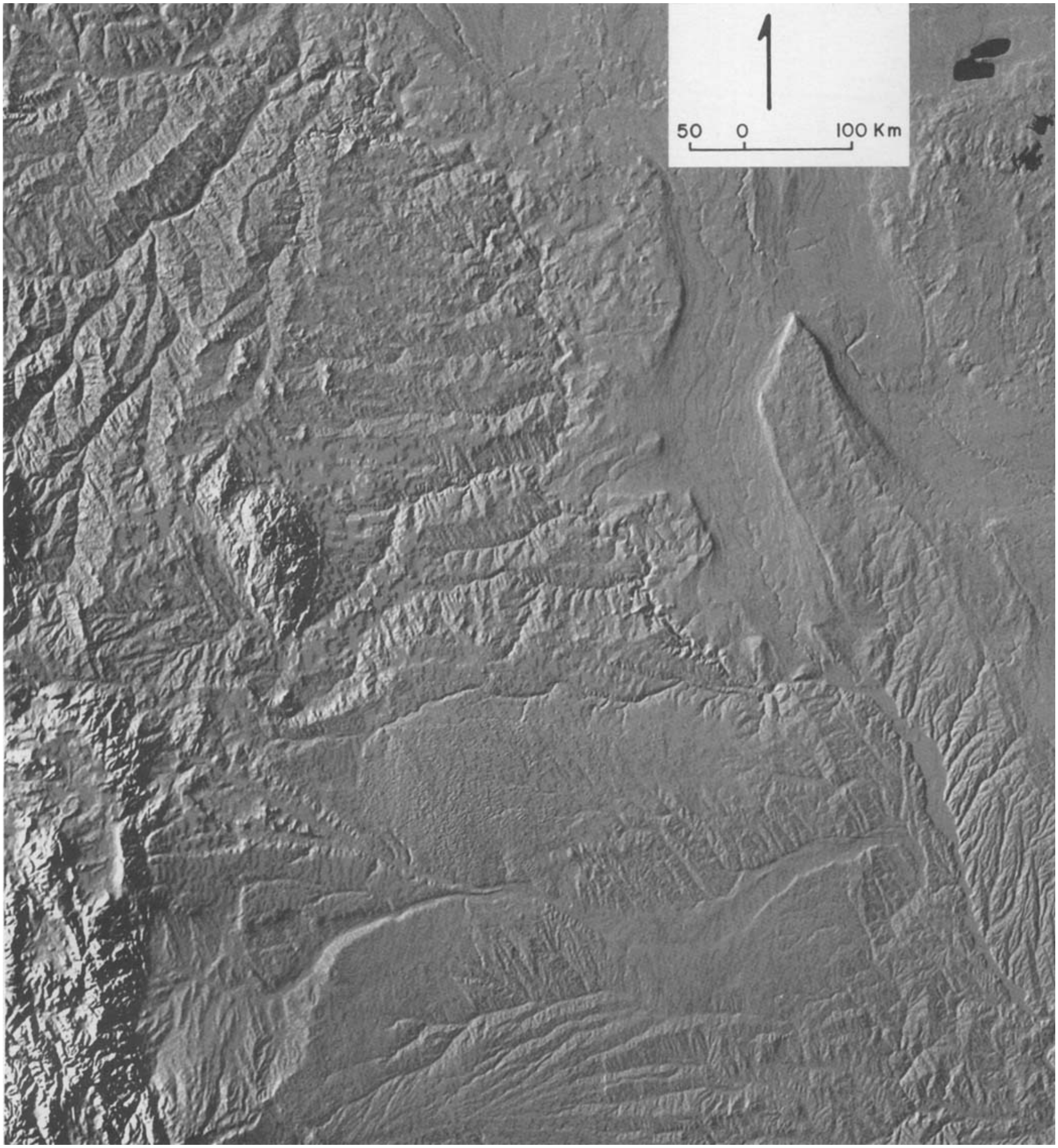

Figure 3. Part of the digital shaded-relief map of the United States including Nebraska, South Dakota, North Dakota, and parts of Minnesota, Iowa, Missouri, Kansas, Colorado, Wyoming, and Montana (Thelin and Pike, 1991). Note the pronounced northwest-southeast topographic grain depicted on the map.

Part of the north side of the North Platte Valley occurs in the southwesternmost part of the study area and slopes to the south and west toward the river valley floor out of the study area. The surface of this area is underlain by Ogallala, Arikaree, and White River sediments progressively to the southwest (Swinehart, et al., 1985).

GEOMORPHOLOGY

At a scale less than the size of the physiographic divisions just noted above, elongate northwest-southeast hills and valleys are dominant features which have been recognized for many years in the Alliance Quadrangle, and across

major parts of the Northern Great Plains (Figs. 3 and 4). The earliest topographic maps of parts of the Nebraska Panhandle prepared by the U.S. Geological Survey around 1900 show these features. More recent topographic maps at scales ranging from 1:250,000 to 1:24,000 also depict them, as do aerial photographs, and satellite images. More recently a synthetic-aperture radar imagery map (Anonymous, 1988; See Fig. 1, this paper) and a digital shaded-relief map (Thelin and Pike, 1991; See Fig. 3, this paper) have also shown these landforms.

Results of research on aligned drainages and other features of the Great Plains have been published since at least the late 1920's. Russell (1929) was perhaps the first researcher to write about the alignment of hills and valleys in parts of the Great Plains states of Montana, North and South Dakota, Wyoming and Nebraska. He explored the possibilities of structural or eolian control of drainage alignments modified by subsequent fluvial erosion and concluded that eolian processes were usually responsible for the alignments. Russell felt that sand deposition followed by later stream erosion were causal. Flint (1955, p. 156-160; Flint, 1971) observed and discussed the origin of similar features in central and eastern South Dakota. He supported the eolian origin and noted that the strongest prevailing winds in the area today are from the northwest. White (1961) also supported the idea of an eolian origin, but Rahn and Frazee (1974) concluded that the primary control of such drainage alignments in parts of South Dakota was structural, either developed along faults or joints in the Cretaceous Pierre Shale. Parallel drainages in Alberta were attributed to the erosive actions of Chinook winds (Beaty, 1975), a conclusion supported in that area by Rahn (1976), but largely dismissed by Rahn as a mechanism for formation of similar features in western South Dakota. Rahn (1976) concluded that drainages in that area form along fracture traces and are oblique to the prevailing winds in the area. More recently, Wells (1983) discussed the eolian origin of the Nebraska Sandhills region.

Parallel and subparallel hills and valleys occur across most parts of the Alliance Quadrangle (Fig. 1) and for that matter across much of the Great Plains from Montana to Kansas (Fig. 3). This geomorphic development forms on lands underlain by shales (Pierre Hills), sandstones (Box Butte Tableland), eolian sands (Sand Hills) and loess (Fig. 4). Fracturing does occur in the shales and the sandstones, but is not obvious in loess and not generally present in loose eolian sand. Drainage alignments developed in loess in parts of Keith County, Nebraska, south-southeast of the Alliance Quadrangle, are similar in orientation to drainage alignments developed to the west of the loess area on sandstones of the Ogallala Group capping tablelands, but are dissimilar to most drainages developed in Ogallala rocks topographically below the loess. In this case wind appears to be responsible for the alignments on uplands. Structural control is not likely in most of this area because it should show up in the underlying strata as well, and, for the most part, it does not. If a regional fracture pattern is responsible for the regional pattern of parallel elongate hills and valleys as Thelin and Pike (1991) suggest, that pattern is not obvious in outcrop.

Both Thelin and Pike (1991) and Simpson and Anders (1992) report that the direction of lighting (300° on the shaded-relief map) may be responsible for exaggerating northwest-southeast trending topographic features. While this certainly is true, I agree with Thelin and Pike that the preferred alignment is real. It shows up in aerial photographs, topographic maps, and, best of all, on the ground.

There are two trends to the topographic alignments on the Alliance Quadrangle. The most common one has long axes of hills and valleys trending N40°-50°W and forms on shales, sandstones, and most eolian sands. It is the same as the trend in Keith County loesses to the south-southeast and in other parts of the Great Plains from Montana to Kansas (Figs. 2-4). The second trend direction is exhibited in one set of dunes in the Sand Hills (Fig. 2, area 6) where the long axes of parabolic dunes are >S50°E. This same trend also occurs on hill tops and dunes on the south side of the North Platte Valley in Keith County below the loess capping the adjacent tablelands to the south. If winds are largely responsible for both sets of trends, as they appear to be, then either two periods of eolian activity are indicated or perhaps the prevailing wind direction was affected by proximity to the river valley.

Another geomorphic feature that shows up on the radar image (Fig. 1) is inverted topography. Several examples can be seen easily at the original published scale of the image, 1:250,000 (Fig. 5). Inverted topography develops in this area when river channels are eroded into fine grained siltstones and are subsequently filled with coarser grained deposits. Later channel migration and downcutting often occurs in the finer grained units that formed the old bedrock valley sides and divides rather than in the coarser deposits, probably because these absorb water more readily than do the finer grained rocks. Thus, siltstones are eroded to form new valleys with the coarser deposits, which filled river inner channels, capping divides.

LINEAMENTS AND STRUCTURAL GEOLOGY

Numerous lineaments that do not have the orientation of landforms noted above are present in the area (Figs. 1,6). These are probably structural in origin. Perhaps the first published mention of structural features in northwestern Nebraska was by Darton (1903), who noted and included a photograph of a fault cutting strata in Dawes County. Cook (1915) reported an uplift in the vicinity of Agate on the Niobrara River south of Harrison, Nebraska, and subsequently elaborated on this in an effort to get petroleum companies interested in the region (Schramm and Cook, 1921). More recently, theses on structural geology were written by graduate students at the University of Nebraska (Sabatka, 1953; Moore, 1954, 1970). Schultz and Stout (1955) noted a fault at Toadstool Park northwest of Crawford, Nebraska. Structural features were mapped in published form for the first time for the Alliance Quadrangle and adjacent areas by Osterwald and Dean (1958). DeGraw (1971) later published refined structural maps including the area of the Alliance Quadrangle, while Hunt, in a series of papers, mapped a number of faults in Sioux County, Nebraska, from the Niobrara Valley at Agate to the Pierre Hills north of Harrison (Hunt, 1977, 1981, 1990). Wyoming Fuel Company (1983) and Collings and Knode (1984) reported on the area around a major uranium discovery east of

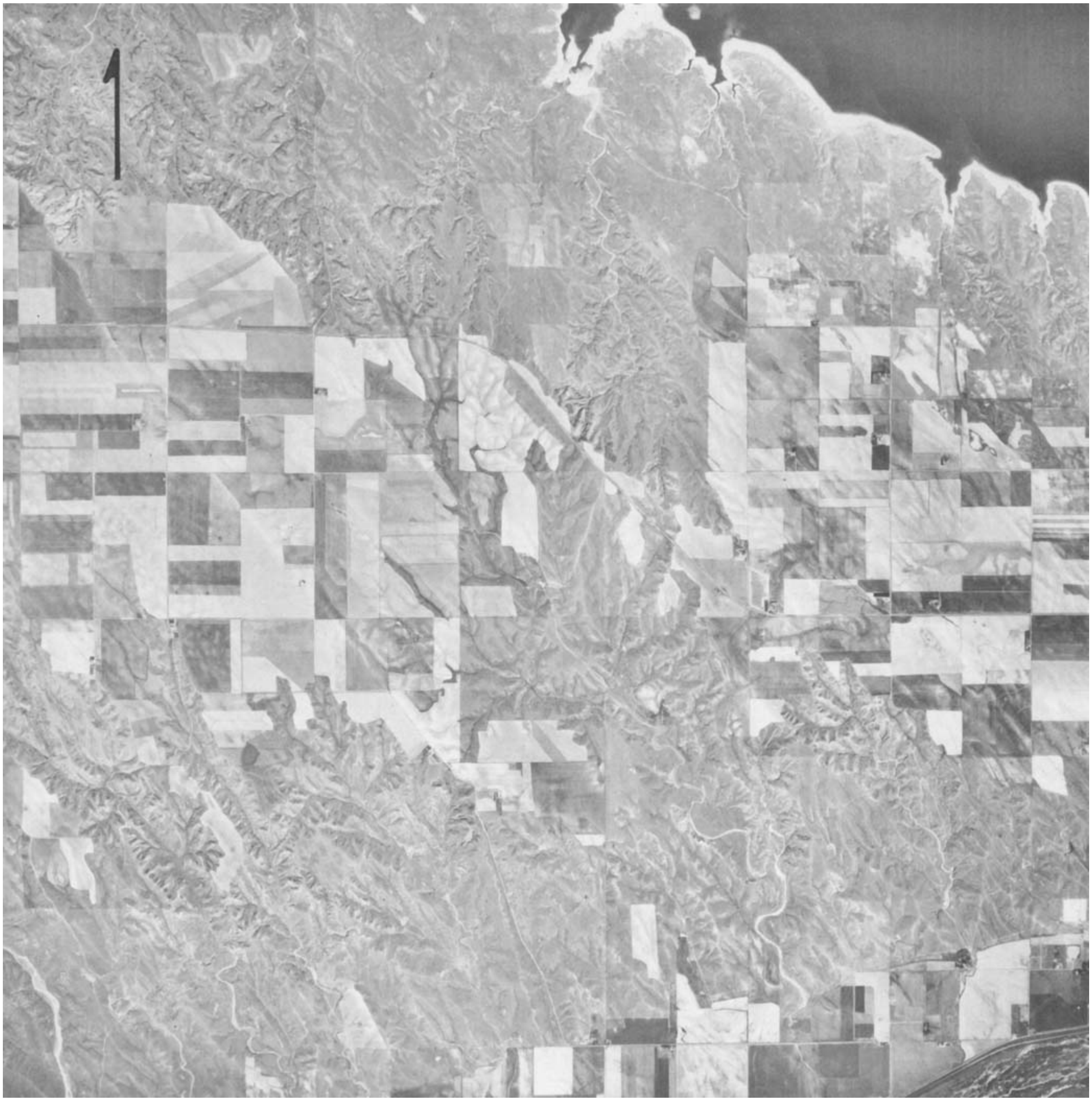

Figure 4. Northwest-southeast topographic grain on the divide ridge between the North and South Platte rivers, Keith County, Nebraska. Both valleys and ridges on this divide are underlain by Quaternary loess.

Crawford, Nebraska. Two recent reports on the regional structure of the Nebraska Panhandle have also been published (Tedford, et al., 1985; Swinehart, et al., 1985), as has one including structures beneath the Nebraska Sand Hills (Swinehart and Diffendal, 1990).

Structural features have been mapped in southwestern South Dakota and east-central Wyoming that either do or may extend into the area of the Alliance Quadrangle. In South Dakota, Darton (1902) and Darton and Tangier Smith (1904) reported on anticlinal folds in Cretaceous rocks at the south end of the Black Hills in the vicinity of the South Dakota-Nebraska border. These three anticlines plunge to the southwest, south, and south-southeast respectively from west to east. Rothrock (1931a, 1931b, 1949) later mapped and described these structures in greater detail. In Wyoming, Love and Christiansen (1985) mapped three northeast-southwest striking faults in east-central Wyoming that might extend into the Alliance Quadrangle. Ahlbrandt and Groen (1985) show northeast-southwest trending faults in east-central Wyoming associated with the Sybille Lineament, all of which also can be projected into the Alliance Quadrangle area.

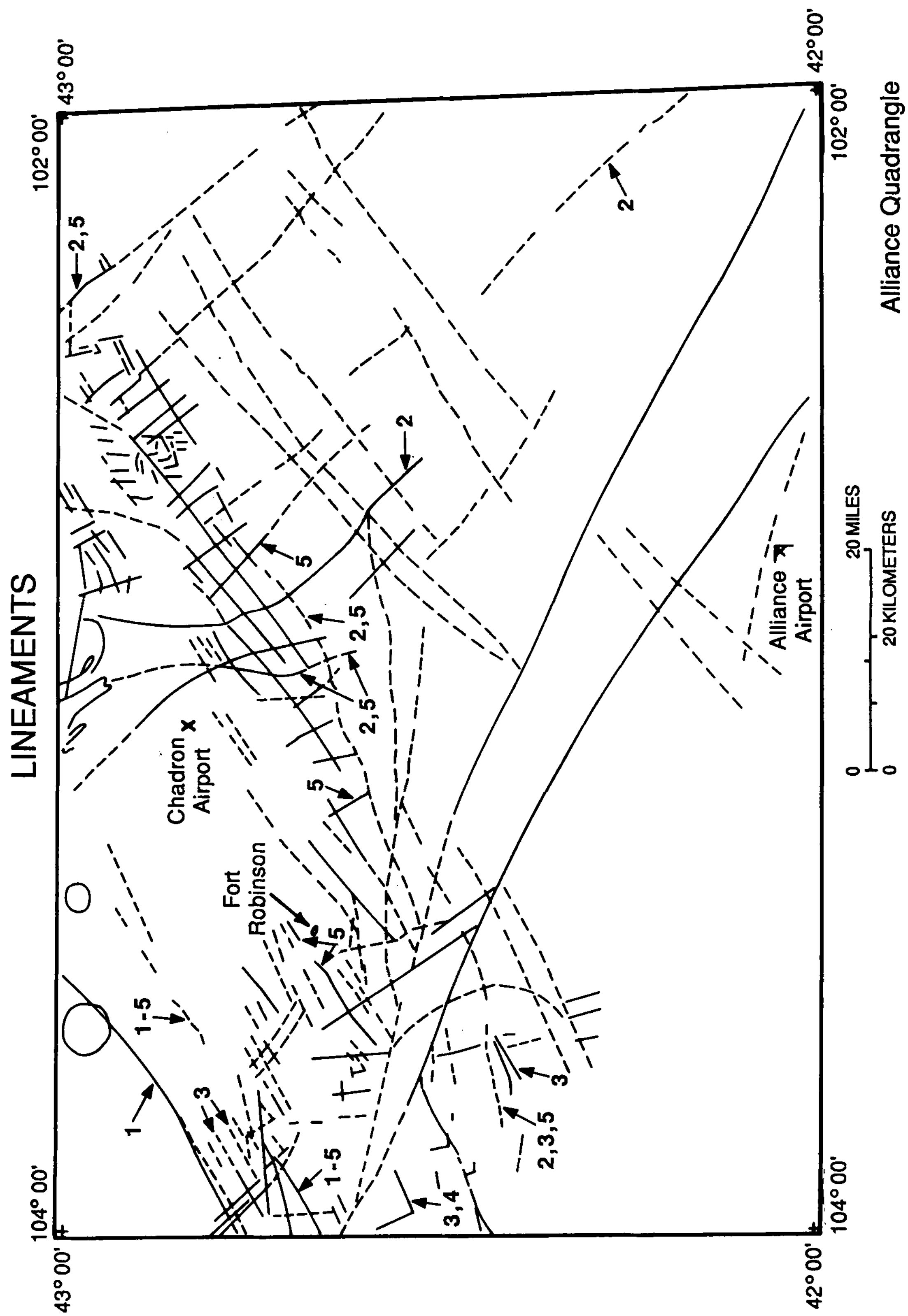

Figure 5. Examples of inverted topography on the Alliance Quadrangle. Fluvial deposits marking the positions of the deepest parts of valleys today cap ridges. Compare trends with Fig. 1.

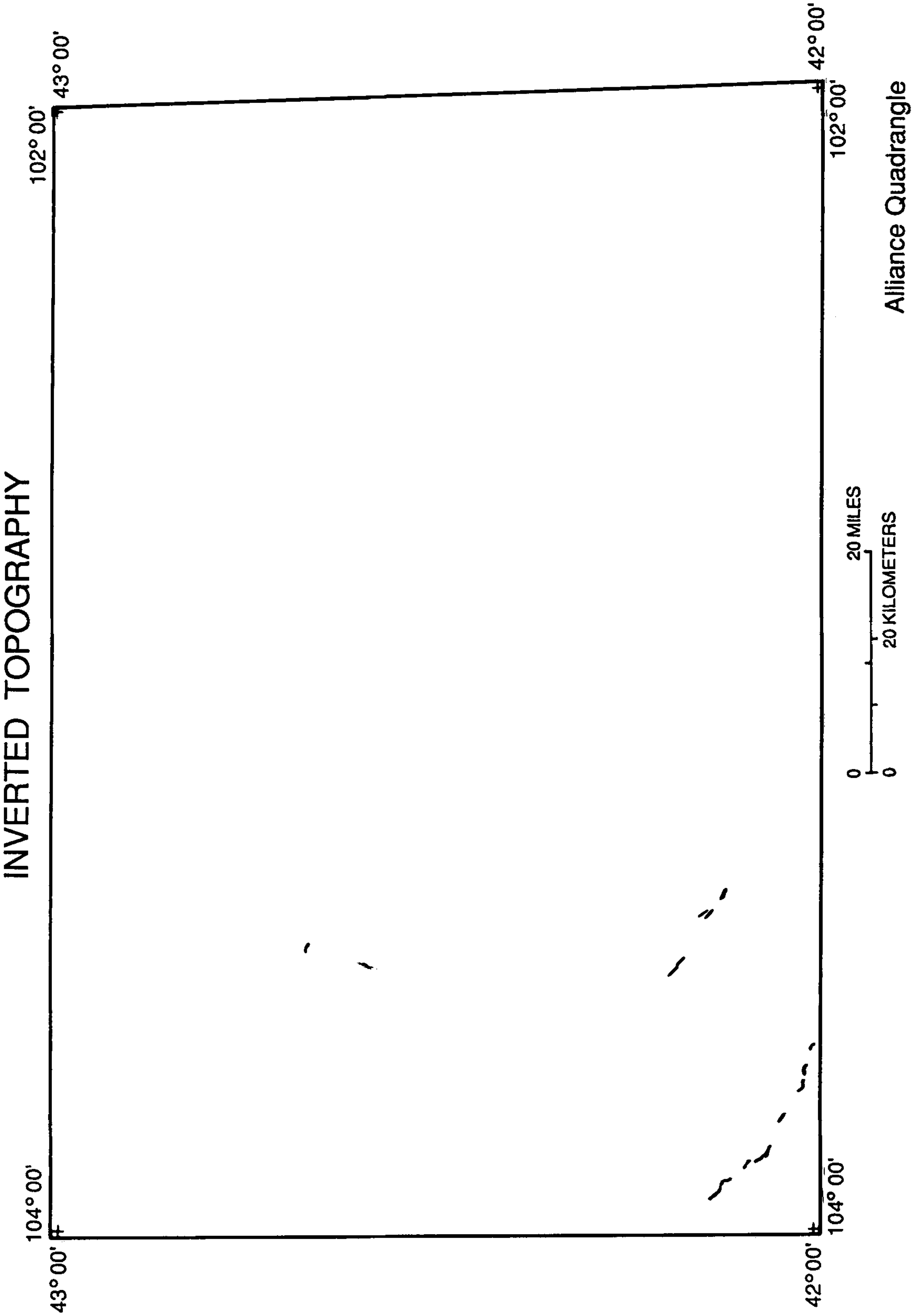

Figure 6. Principal lineaments visible on Fig. 1. Numbers indicate lineaments that match completely or in part mapped faults shown in the following references, cited at end of text: 1. Ahlbrandt and Groen, 1987; 2. DeGraw, 1971; 3. Hunt, 1977, 1981, 1990; 4. Love and Christiansen, 1985; 5. Swinehart, et al., 1985.

Lineaments were observed on aerial photographs and satellite images in western Nebraska by Swinehart (1972) and subsequently described over a larger area of Nebraska (Carlson and Swinehart, 1973). Souders (1981) prepared a lineament map as part of a major groundwater study of parts of two counties located in the Alliance Quadrangle. Swinehart (1975) also discussed the uses of fracture traces for locating water wells in western Nebraska south of the Alliance Quadrangle. Recently, Diffendal (1992) reported briefly on the uses of radar images and shaded relief maps to locate structures and geomorphic features in northwestern Nebraska.

Many lineaments can be seen on the synthetic-aperture radar image of the Alliance Quadrangle (Figs. 1,6). On the original 1:250,000 scale mosaic far more lineaments are present than I have depicted on Figure 6. Only the most prominent to my eye are shown there. Two general sets of lineaments appear to dominate those illustrated, a northeast trending set and a northwest trending set. The northeast trending set tends to cross drainages, while the northwest trending set includes many lineaments that follow drainages. Several groups of lineaments trend in other directions. Lineaments in one small area on the east side of the north-central part of the quadrangle have a chevronlike pattern (Fig. 6). To the northwest of these the lineaments form a fan shape about the Chadron Dome (Fig. 6; Moore, 1954). Some lineaments trend approximately north-south and east-west south of Harrison and west of Crawford on the Pine Ridge. Two nearly circular drainage features occur to the northeast of Harrison near the Nebraska-South Dakota border. A curved feature crosses the Niobrara Valley east of Agate and south-southwest of Fort Robinson (Fig. 6).

Large numbers of lineaments on the Pine Ridge are probably related to the competence of the rocks beneath the surface of the ridge and to the fact that these rocks are deformed and have southerly dips (Swinehart, et al., 1985). The siltstones and sandstones of the Arikaree and White River groups have more widely spaced joints and probably exhibit more brittle behavior than does the Pierre Shale.

Several lineaments coincide with mapped faults or fault segments in Nebraska (Fig. 6). Some of these also appear to be extensions of faults mapped in Wyoming near the Nebraska border. Many of the mapped faults in Nebraska are located only approximately and may in fact lie along some of the lineaments shown in Figure 6, particularly in the northeastern part of the map area (compare Fig. 6 with maps in DeGraw, 1971, and Swinehart, et al., 1985).

Some lineaments mapped in earlier studies have proven to be highways, pipeline or highline traces, trails (either vehicular or animal), railroads, or other cultural features. Careful examinations of current and older maps revealed that none of the mapped lineaments (Fig. 6) appears to be of this origin. Since the radar image is a composite made of northwest-southeast strips some of the lineaments might also be artifacts of the merging of these strips. The two lineaments nearly continuous across the quadrangle, trending generally southeast were compared with the mosaic strip boundaries and do not appear to follow them for any great distance. In fact they cross from one strip to another and are, thus, probably real features.

The two prominent lineaments referred to above seem to reflect geologic changes at the surface and in the subsurface that may be related to folds, or more probably faults. In the south-central part of the quadrangle they parallel trends in outcropping formation boundaries and also coincide with lows on the top of the informally named Brown Siltstone member of the Brule Formation, White River Group (Souders, et al., 1979). Extended to the southeast and onto the North Platte 1° × 2° geologic map area, they appear to follow trends of the thickest Ogallala Group rocks beneath the Sand Hills (Diffendal, 1991). These lineaments seem to disrupt the surface dunes of the Sand Hills and may be evidence of old faults with very recent renewed activity.

CONCLUSIONS

Numerous northwest-southeast trending hills and valleys occur across the Alliance Quadrangle and extend across other parts of the Great Plains from Montana southeast at least to Kansas. These parallel or subparallel geomorphic features appear to coincide most closely with late Pleistocene to recent prevailing winds in the region (Calder, 1974; CLIMAP Project Members, 1976; Gates, 1976; Ahlbrandt, et al., 1983; Guthrie, 1990). While they are probably principally due to wind erosion modified later by running water, in some places outside of northwestern Nebraska some of them may be structurally related in part or whole. Some of the major lineaments crossing the map area and shown on synthetic-aperture radar imagery appear to be traces of faults. Others may be due to either jointing or faulting, but only on-the-ground field work, perhaps combined with carefully selected test drilling will verify which of these two structural features is the cause of any single lineament. Both synthetic-aperture mosaics and digital shaded-relief maps are useful tools for the study of geomorphic and structural development of regions.

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