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Project Plan—Surficial Geologic Mapping and Hydrogeologic Framework Studies in the Greater Platte River Basins (Central Great Plains) in Support of Ecosystem and Climate Change Research

Open-File Report 2011–1010

U. S. Department of the Interior
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Cover: (Clockwise) South Platte River near Orchard, Colorado; Rocky Ford Rapids, Niobrara River, Nebraska; Wray dune field, eastern Colorado.

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By Margaret E. Berry, Scott C. Lundstrom, Janet L. Slate, Daniel R. Muhs, David A. Sawyer, and Darren R. Van Sistine

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Acronyms

CEN	Climate Effects Network
CGGSC	Crustal Geophysics and Geochemistry Science Center
CGS	Colorado Geological Survey
CSD	Conservation and Survey Division
GECSC	Geology and Environmental Change Science Center
GPRB	Greater Platte River Basins
KGS	Kansas Geological Survey
KSWSC	Kansas Water Science Center
NCGMP	National Cooperative Geologic Mapping Program
NEWSC	Nebraska Water Science Center
NIOB	Niobrara National Scenic River
NPS	National Park Service
NRD	Nebraska Natural Resource Districts
UNL	University of Nebraska-Lincoln
USGS	U.S. Geological Survey
ka	kilo-annum, 10^3 years

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Abstract

Geologic mapping studies are underway to help define the geologic framework for integrated ecosystem and climate change research in the Greater Platte River Basins, an ecoregion being targeted for collaborative observation and research by the Climate Effects Network (CEN) of the U.S. Geological Survey (USGS) Global Change Program. Geologic mapping and associated geochronological research provide information about physical and chemical properties, distribution, age, origin, and stratigraphic relations of surficial geologic deposits for reconstructing geologic and hydrologic history and for recognizing geomorphic response to climate change that is recorded in the geologic record.

Planned surficial geologic mapping and research under the new "Greater Platte River Basins and Northern Plains Geologic Framework Studies Project" primarily focuses on three areas: (1) the South Platte River on the drought-prone eastern plains of Colorado, a semiarid environment where geomorphic systems tend to be highly sensitive to climate change; (2) the Niobrara National Scenic River in northern Nebraska, situated at the crossroads of several ecosystems, where many plant and animal species are near the limits of their usual geographic range, and geomorphic systems may be near threshold limits; and (3) the Crescent Lake Wildlife Refuge area in the western Nebraska Sand Hills, where dune migration during past episodes of eolian sand activity blocked stream drainages and created numerous lakes. In each of these areas, the geologic records of fluvial and eolian systems are intimately connected and reflective of past climate change. Large-scale geologic mapping in these areas, which will complement ongoing studies by other researchers, will lead to a better understanding of how climate change has affected the geomorphic systems in the past, and how it might affect them in the future. This information is vital to preserving and sustaining healthy human and wildlife habitats, adequate water supplies, and operational infrastructure.

Planned hydrogeologic framework studies under the new "Greater Platte River Basins and Northern Plains Geologic Framework Studies Project" focus primarily on groundwater issues in a fourth area, the Republican River drainage of southern Nebraska and northern Kansas. Sustainability of water in the basin has been a key topic of concern between states sharing the water supply, a concern intensified by the possibility of further diminishing water resources as climate changes. New digital geologic mapping of selected areas will improve understanding of the complex geologic framework that affects groundwater flow and groundwater-surface water interactions in and around the basin, and help address the major issue of water sustainability.

Introduction

The Greater Platte River Basins (GPRB; Thormodsgard, 2009) area spans a central part of the midcontinent and Great Plains from the Rocky Mountains on the west to the Missouri River on the east, and is defined to include drainage areas of the Platte, Niobrara, and Republican Rivers, the Rainwater Basin (LaGrange, 2005), and other adjoining areas overlying the northern High Plains aquifer (fig. 1). The GPRB contains abundant surficial deposits that were sensitive to, or are reflective of, the climate under which they formed: deposits from multiple glaciations in the mountain headwaters of the North and South Platte Rivers and from continental ice sheets in eastern Nebraska; fluvial terraces (ranging from Tertiary to Holocene in age) along the rivers and streams; vast areas of eolian sand in the Nebraska Sand Hills and other dune fields (recording multiple episodes of dune activity); thick sequences of windblown silt (loess); and sediment deposited in numerous lakes and wetlands (Swinehart and others, 1994; Soller and others, 2009). In addition, the GPRB overlies and contributes surface water to the High Plains aquifer, a nationally important groundwater system that underlies parts of eight states and sustains one of the major agricultural areas of the United States (Weeks and others, 1988; Luckey and others, 1988; McMahon and others, 2007). The area also provides critical nesting habitat for birds such as plovers and terns, and roosting habitat for cranes and other migratory birds that travel through the Central Flyway of North America (Committee on Endangered and Threatened Species in the Platte River Basin, National Research Council, 2004; http://flyways.us/flyways/info). This broad area, containing fragile ecosystems that could be further threatened by changes in climate and land use, has been identified by the USGS and the University of Nebraska-Lincoln as a region where intensive collaborative research could lead to a better understanding of climate change and what might be done to adapt to or mitigate its adverse effects to ecosystems and to humans (University of Nebraska-Lincoln Office of Research, 2008). The need for robust data on the geologic framework of ecosystems in the GPRB has been acknowledged in proceedings from the 2008 Climate Change Workshop (University of Nebraska-Lincoln Office of Research, 2008) and in draft reports by researchers developing a multidisciplinary science plan for the GPRB.

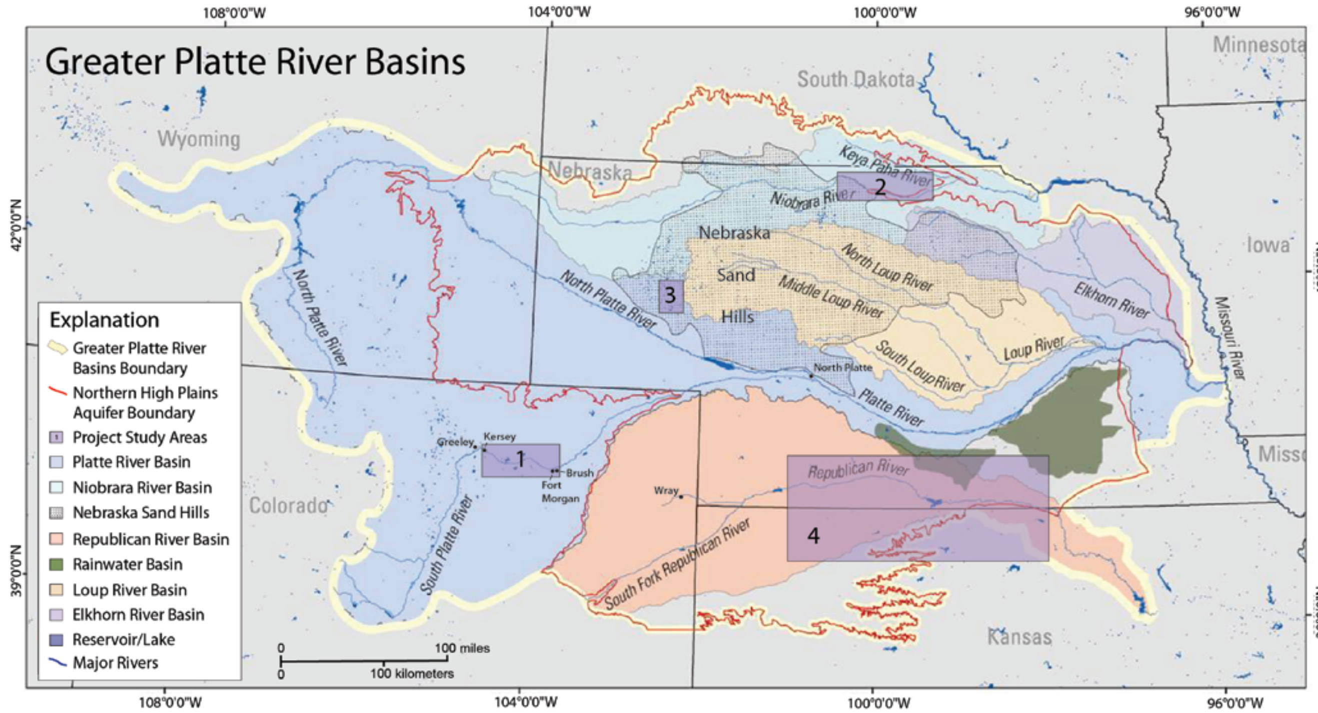

Figure 1. Map showing the Greater Platte River Basins, northern part of the High Plains aquifer, and general study areas targeted for this project: (1) South Platte River corridor, (2) Niobrara National Scenic River, (3) Crescent Lake Wildlife Refuge area, and (4) Republican River area. Eolian sediments cover much of the GPRB although only the Nebraska Sand Hills are shown here. Base map taken from Thormodsgard (2009).

Project Objectives

The USGS Geology and Environmental Change Science Center (GECSC) has initiated surficial geologic mapping and hydrogeologic framework studies in the GPRB in support of ecosystem and climate change research ("Greater Platte River Basins and Northern Plains Geologic Framework Studies Project"); these studies are funded chiefly by the USGS National Cooperative Geologic Mapping Program (NCGMP; *http://ncgmp.usgs.gov/*), with supplemental contributions from the USGS Global Change Program (*http://www.usgs.gov/global_change/*). The overall objective of these studies is to help define the geologic framework of ecosystems in the GPRB by providing information about physical properties, geochemistry, stratigraphic relations, age, origin, and areal distribution of geologic mapping units. Goals are to obtain a better understanding of (1) past climate information recorded in the geologic record, and (2) geomorphic or climatic thresholds that may have triggered major changes in the ecosystems in the past. This information will be vital to regional land-use decision makers and managers trying to anticipate effects of future climate change and make informed choices among competing land uses.

Our goal has been to develop this project in partnership with the USGS Global Change Program, and to collaborate with other agencies and academia conducting research in the GPRB. This project directly supports the USGS Science Strategy by evaluating past interactions between climate, earth surface processes, and ecosystems (relevant to understanding ecosystem sustainability, and wildlife and human health), and generating new information for modeling aquifer systems that can be used to manage and protect drinking-water supplies. The project also will be relevant to addressing natural hazards, through identification of floods and wildfires recorded in the geologic record and assessing mineral and aggregate resources.

Strategy and Approach

Preliminary objectives of this project have been to identify key areas where new surficial geologic mapping and hydrogeologic framework studies could address paleoclimate, ecosystem, and/or groundwater-related issues within the GPRB. As a result of numerous meetings and discussions with collaborators, assessing the current state of geologic mapping (Appendix) and other relevant geologic data, and conducting field reconnaissance, we have identified three study areas for new, detailed surficial geologic mapping subtasks that will address major ecosystem and climate change issues: (1) the South Platte River corridor on the eastern plains of Colorado; (2) the Niobrara National Scenic River, transecting the northern Sand Hills in Nebraska; and (3) the Crescent Lake Wildlife Refuge area, in the western Nebraska Sand Hills (fig. 1). In each of these areas, the geologic records of fluvial and eolian systems are intimately interrelated and reflective of past changes in climate. Large-scale geologic mapping will emphasize river floodplain and terrace deposits; sand dune, interdune, and dune-dammed lake deposits; windblown silt deposits, and relations among these different types of surficial deposits, and will complement ongoing studies by other researchers in a multiple of disciplines. In addition, the mapping will identify areas of the landscape susceptible to sediment or soil erosion, which affects soil productivity, sediment load in streams and lakes, water quality, and fish and wildlife habitat, and can lead to future collaboration with biologists working in the GPRB.

These surficial geologic mapping subtasks of our NCGMP project are being developed in an integrated fashion with the "Impacts of Climate Change on Coastal and Eolian Landscapes Project" (funded by the USGS Office of Global Change) through a joint subtask entitled "Eolian Sediments in the Greater Platte River Basins, Great Plains. " One objective of the eolian sediments subtask is to understand the dynamics of sand dune formation and activity in the GPRB. A second objective is to infer past climates from loess (windblown silt) records and compare results with general circulation models.

In addition, the Republican River area of southern Nebraska and northern Kansas (fig. 1) has been identified as a watershed where hydrogeologic framework studies could help address critical issues concerning water sustainability in the basin. New digital geologic mapping of selected areas will improve understanding of the complex geologic framework that affects groundwater flow and groundwater-surface water interactions in and around the basin, and lead to a better understanding of how best to model and manage the groundwater resources.

Surficial Geologic Mapping Studies

Methodology

Objectives of the surficial geologic mapping task will be addressed through large-scale (generally 1:24,000) digital geologic mapping, sedimentologic, and stratigraphic studies (aided by drilling or backhoe excavation where appropriate and feasible) of surficial geologic materials using a combination of field, remote sensing, geochronology and other laboratory techniques, and incorporating geophysical, well, or other subsurface data where available. Geochronology will be established through dating (primarily radiocarbon and luminescence methods), tephrochronolgy, geoarchaeology, and paleontology where applicable. Surface soils, paleosols, and peat deposits will be described and sampled for relative age assessment, radiocarbon dating, and/or inferences about paleoenvironment. For the Crescent Lake Wildlife Refuge area, historical study will be conducted using archival aerial photography and available written records. Digital maps will be published at a scale determined most appropriate to convey significant results.

Communication Plan

This task is being coordinated with other scientific entities, including the USGS Nebraska Water Science Center (NEWSC), the USGS Crustal Geophysics and Geochemistry Science Center (CGGSC), the CEN of the USGS Global Change Program, the University of Nebraska-Lincoln (UNL) Conservation and Survey Division (CSD), several Nebraska Natural Resource Districts (NRD), the National Park Service (NPS), and the Colorado Geological Survey (CGS). Task members will communicate frequently with these agencies about our research activities. Project results will be communicated through a variety of methods: (1) poster or oral presentations at professional meetings; (2) field trips with collaborators and other interested parties; (3) USGS publications (maps, reports, and/or fact sheets); (4) peer-reviewed scientific journal articles or book chapters; (5) a project-Web site, which could be of interest to scientists, stakeholders, and the general public; and, (6) if results warrant it, newspapers or other news media.

Subtask: South Platte River Corridor, Eastern Colorado

For more than half its length, the Platte River system is made up of two rivers, the South and North Platte, both of which have headwaters in the Colorado Rocky Mountains and merge downstream to form the central Platte River near North Platte, Nebraska (fig. 1). The South Platte River flows across the semiarid, short-grass prairie of eastern Colorado, a region highly susceptible to drought (Madole, 1994). Part of the High Plains Ecoregion, the area is higher and drier than areas to the east, with a mean annual precipitation of 12-20 inches (about 30-50 cm) and a mesic temperature regime (Chapman and others, 2006). In this type of semiarid, drought-prone environment, geomorphic systems tend to be highly sensitive to climate change, and surficial deposits provide a past record of system response to that change (for example, Miao and others, 2007). Determining past system response can help predict potential future response to climate change that might have adverse effects on ecosystems and society. The purpose of this subtask is to better understand the fluvial record of the South Platte River on the eastern plains of Colorado, and to relate the record for the South Platte River to records for the North Platte River, central Platte River, and eolian deposits of the GPRB, through collaborative work with other researchers.

Geologic Setting

Nine topographic levels that define the tops of fluvial terraces have been recognized along the South Platte River, including: pre-Rocky Flats alluvium (mapped as Pliocene Nussbaum Alluvium in some studies), early Pleistocene Rocky Flats, early middle Pleistocene Verdos (about 640 thousand years [ka]), middle Pleistocene Slocum, late middle Pleistocene Louviers (thought to be correlative in age to Bull Lake till), and late Pleistocene Broadway (thought to be correlative in age to Pinedale till) Alluviums, and Holocene pre-Piney Creek alluvium, Piney Creek Alluvium, and post-Piney Creek alluvium (Madole, 1991; Lindsey and others, 2005). The presence of additional, less distinct Holocene alluvial units is suggested by data from some archeological sites (Madole, 1991).

In addition to fluvial terraces, multiple generations of eolian silt and sand deposits, generated in part from fluvial sediments of the South Platte River, cover much of the terrain (Madole, 1991, 1995;

Jorgensen, 1992; Forman and others, 1995; Muhs and others, 1996, 1999a, 1999b; Aleinikoff and others, 1999; Madole and others, 2005; Aleinikoff and Muhs, 2010). Although the eolian sand is stabilized currently by vegetation, dune stability probably is near threshold limits under the present climate, and therefore slight changes in climate or land use could result in future widespread eolian sand transport (Madole, 1994; Muhs and Maat, 1993; Muhs and Holliday, 1995).

Mapping and Research Plan

Recent geologic mapping efforts in the South Platte drainage have focused on the mountainous headwaters and the urban corridor along the Colorado Front Range (Appendix). Aside from geoarchaeological and pedologic work on late Pleistocene and Holocene terraces near Kersey, Colorado (Holliday, 1987; McFaul and others, 1994; Muhs and others, 1996), little geologic mapping and research on fluvial deposits has been done along the South Platte River corridor downstream from Greeley, Colorado, since the seminal work of Glenn Scott on the Sterling 1° x 2° quadrangle (Scott, 1978; 1982). Much remains to be learned about the fluvial history for this part of the river. Our objectives are to map, characterize, and develop a geochronology and stratigraphy for surficial deposits along a portion of the South Platte River corridor in eastern Colorado. Our work will build on research recently published on Quaternary alluvial deposits of the South Platte River and tributaries in the urban corridor region west of the study area (Lindsey and others, 2005), new geologic mapping in the mountains and urban corridor along the Front Range (Kellogg and others, 2008; Cole and Braddock, 2009; mapping in progress, Appendix), and older geologic mapping within the study area (Greeley 1° x 2° quadrangle, Braddock and Cole, 1978; Sterling 1° x 2° quadrangle, Scott, 1978, 1982; Orchard, Weldona, and Fort Morgan 7 1/2' quadrangles, Gardner, 1967). Specific areas for initial mapping and research will be affected by availability of field exposures and land access, but our plan is to focus on the area between Kersey and Brush, Colo. This stretch of river has been affected by past alpine glaciations in the headwaters, and more locally, by past droughts severe enough to mobilize dune sand and produce significant deposits of wind-blown silt in the basin.

This research complements work conducted through STATEMAP (NCGMP’s matching-funds grant program with State geological surveys; *http://ncgmp.usgs.gov/ncgmpabout/statemap*) by the UNL CSD on the North Platte and central Platte rivers in Nebraska, for which the fluvial history also is poorly understood. This collaborative strategy will allow us to synthesize a more complete picture of the fluvial history of the Platte River system by producing data for a larger portion of the river basin, filling a significant data gap and strengthening the significance of both FEDMAP (NCGMP’s program that funds Federal geologic mapping projects; *http://ncgmp.usgs.gov/ncgmpabout/fedmap*) and STATEMAP results. Our NCGMP project is committed to fostering collaborative STATEMAP-FEDMAP work, and therefore could assist with some mapping on the North Platte/central Platte Rivers in Nebraska if needed. The research also complements work being conducted on eolian sediments in the GPRB, which is being conducted in an integrated fashion as a subtask (described in subtask: Eolian Sediments in the Greater Platte River Basins, Great Plains) under both our NCGMP project and the “Impacts of Climate Change on Coastal and Eolian Landscapes Project” (funded by the USGS Office of Global Change).

Subtask: Niobrara National Scenic River, Nebraska

The Niobrara National Scenic River (NIOB), located in northern Nebraska, is situated at the midcontinental crossroads of several ecosystems (National Park Service, 2007), and is renowned for its biological diversity (Johnsgard, 2007). Climate change has the potential of having significant effect in this ecoregion, where many plant and animal species are near their geographic range limits. Geomorphic systems also may be near threshold limits in this ecoregion, and therefore may be particularly responsive to climate change; river response to climate change has been noted during historic time, when prolonged drought of the 1930s induced changes in river channel width (Buchanan, 1981). For these reasons, the unique setting of the NIOB makes it a prime area for detailed geologic mapping and stratigraphic studies focused on the geologic framework of ecosystems and effects of climate change on the fluvial system. In addition, the NIOB lacks geologic map coverage for the NPS Geologic Resources Inventory (GRI) (Bruce Heise, written commun., 2010), and a GRI scoping meeting attended by NPS and USGS staff, held in August 2008, identified better quality geologic map coverage as a need for the NIOB.

Geologic Setting

The NIOB is a 76-mile stretch of river situated at the northern edge of the Nebraska Sand Hills, in an area with 18-20 inches (46-51 cm) of mean annual precipitation and a mesic temperature regime (Chapman and others, 2001). The NIOB river corridor contains abundant surficial deposits that reflect the history of the fluvial system. Alexander and others (2010) recognize four groups of fluvial landforms: low flood plains, inundated most years by the annual peak flood; intermediate flood plains, inundated somewhat less frequently by floods caused by winter ice jams; low terraces, 7–11 ft (2–3.4 m) above median annual discharge; and high terraces, greater than 11 ft (>3.4 m) above median annual discharge. Characterization of the entire suite of terraces was not the focus of their research on modern river channel geometry and hydrogeomorphology, so their surveys did not extend across the full width of the valley (Alexander and others, 2010), but terraces ranging as high as 312 ft (95 m) above the valley floor have been reported (Hearty, 1978). A prominent high terrace, associated with fluvial deposits informally referred to as the Connely Flat beds (Jacobs and others, 2007) and considered late Pleistocene in age, is about 175 ft (53 m) above the valley floor (Diffendal and others, 2008). As many as five terraces are preserved at levels lower than this prominent late Pleistocene terrace (Diffendal and others, 2008). Sand dunes bordering the drainage are stabilized by vegetation, but thick sections of Pleistocene lacustrine sediments found to the west of the NIOB are interpreted as having been deposited in dune-dammed lakes (Jacobs and others, 2007), suggesting that past mobilization of the sand dunes has had a significant effect on the fluvial system.

Mapping and Research Plan

Our goals for this subtask are to map the river corridor along the 76-mile reach designated National Scenic River, and to develop a geochronology and stratigraphy for the surficial-geologic deposits, to satisfy NIOB park needs for a better quality geologic map, and to gain an understanding of how future climate change may affect the Niobrara fluvial system and ecosystems. The prominent high terrace (more than 50 m above the valley floor) described as late Pleistocene in age (Diffendal and others, 2008) poses an intriguing question as to what caused the fluvial system to incise so dramatically in the past, and our goal is to understand better the timing and causes of such river response. Our plan is to coordinate with ongoing fluvial-geomorphologic research being done by the USGS NEWSC (Alexander and others, 2009, 2010), as well as borehole and surface geophysical work being done by the USGS NEWSC and local NRDs in support of groundwater modeling. Our work will build on mapping and research recently published for the O'Neill 1° x 2° quadrangle (Diffendal and others, 2008), which covers the eastern half of the NIOB, and will help fill data gaps in geologic mapping in the western half of the NIOB (Appendix).

Subtask: Crescent Lake Wildlife Refuge Area, Nebraska

The Crescent Lake Wildlife Refuge area is located in the western part of the Nebraska Sand Hills, the largest sand sea in North America. Although relatively dry with 17–19 inches (43–48 cm) of mean annual precipitation, a mesic temperature regime, and a mixed-grass prairie vegetation (Chapman and others, 2001), this part of the Sand Hills is characterized by numerous lakes and wetlands interspersed between the dunes that provide critical roosting habitat for cranes and other migratory birds. Many of the lakes are alkaline, and few to no rivers or streams flow through the area. The sand dunes presently are stabilized by vegetation, but it is unknown how close the landscape is to a critical threshold, and how much additional stress it would take to destabilize the dunefield. Reactivation of dunes in the Sand Hills would have serious effects on agricultural lands, grazing lands, wildlife habitats, and infrastructure.

Geologic Setting

The central Great Plains is a region susceptible to severe, long-term drought (Loope and Swinehart, 2000), which is linked to widespread eolian activity (Mason and others, 2004). Eolian activity has occurred several times in the past 10,000 years (1.0–0.7 ka, 4.5–2.3 ka with peaks centered on 3.8 and 2.5 ka, and a sustained period of eolian activity from 9.6 to 6.5 ka; Miao and others, 2007). Although the dune field was reworked extensively a number of times during the Holocene, it is likely that a dune field also was present during the last glacial period (Muhs and others, 1999b; Loope and Swinehart, 2000; Muhs and others, 2000; Bettis and others, 2003; Mason and others, 2004), and possibly earlier than that, based on the mineralogical maturity of its deposits (Muhs and others, 1997). During past episodes of eolian activity, sand dunes of the western Nebraska Sand Hills migrated across the Blue Creek drainage, burying stream channels and creating dune dams that resulted in the formation of numerous shallow lakes and wetlands (Loope and others, 1995; Mason and others, 1997). These lakes have complex water chemistry, reflecting a complex interaction with the groundwater system (Bleed and Ginsberg, 1990). The lakes vary in size and number seasonally and annually in response to precipitation and evaporation rates, but historic accounts indicate that there also have been changes in lake size and number related to longer climate trends during the 1900s (Bleed and Ginsberg, 1990). It may be that episodic climate changes during the Holocene have caused long-term changes in size and number of lakes, and that a record of those changes is preserved in the interdune wetland and lake sediments; for example, an interdune wetland to the north of the Crescent Lake area has yielded a pollen record indicative of late Pleistocene and Holocene climate changes (Swinehart and others, 1996). To understand such a climate signal, an in depth knowledge of the spatial distribution, sedimentology, hydrogeology, and geologic history of the local dune field, and dune-dammed wetlands and lakes is needed (Loope and others, 1995).

Mapping and Research Plan

Work in the Crescent Lake Wildlife Refuge area is being conducted as part of a collaborative project with the USGS CGGSC and USGS NEWSC, whose teams are collecting airborne geophysical data, interpreting the hydrogeologic framework, and planning future groundwater modeling work; the UNL CSD, whose team is collecting cores and age dating sediments along the airborne transects; and the area NRDs, whose staff can provide critical local insight and experience. Our objectives for this subtask are to understand the climate signal recorded in dune, interdune, dune-dammed lake, wetland, and stream deposits in the Crescent Lakes Wildlife Refuge and surrounding area, through detailed geologic mapping, historic comparative photogeologic mapping, and sediment analyses that complement the work being done by collaborators. Because dune migration would have serious effects on agricultural and grazing lands, wildlife habitats, and infrastructure, a key question for the region centers on how close the Nebraska Sand Hills landscape is to a critical threshold, past which stabilizing vegetation cannot be sustained and sand is remobilized. Our research results will help determine past sensitivity of the geomorphic systems, providing critical information for addressing this question.

The mapping area will focus on the Crescent Lakes Wildlife Refuge and adjacent areas primarily to the north, where numerous lakes occupy interdune areas, but the actual area mapped will be affected by land access, available field exposures, preliminary results of geologic and comparative archival photogeologic mapping, and areas selected for data collection by collaborators.

Subtask: Eolian Sediments in the Greater Platte River Basins, Great Plains

The GPRB occupies a large part of the Great Plains of central North America. It is a semiarid region and like most semiarid regions, experiences a wide range of variability in year-to-year precipitation. This makes the region's geomorphic systems highly sensitive to climate changes. Much of the GPRB is covered with eolian sediments (dune sand, sheet sand, and loess) that are stabilized mostly by vegetation. Reactivation of these deposits is a distinct possibility with shifts in the overall moisture balance, because stabilizing vegetation is dependent highly on precipitation. Effects of future reactivation of eolian sand or loess would be high, and would affect grazing land, agricultural land, wildlife habitats, and infrastructure.

Objectives

Eolian sediments in the GPRB are the focus of a subtask, led by Dan Muhs and funded by the USGS Office of Global Change through the "Impacts of Climate Change on Coastal and Eolian Landscapes Project," being conducted in an integrated fashion with our surficial geologic mapping studies. One objective of this subtask is to understand the dynamics of sand dune formation and activity in the GPRB (for example, Muhs and others, 1996, 1997; Muhs and others, 1999b; Muhs and others, 2000). A second objective is to infer past climates from loess (windblown silt) records and compare results with general circulation models (Muhs and others, 1999b, 2008); paleoclimate data are fundamental to understanding future climate change and its potential effect. Loess is widespread in the central United States and contains one of the most complete records of the last glacial period and the Holocene (Mason and others, 2008). Past wind directions are inferred from loess properties, and past vegetation can be inferred from paleosols within loess (Muhs and others, 2008).

Methodology

Eolian studies involve mapping, in the field and on aerial photographs, sampling and dating (radiocarbon and luminescence methods) stratigraphic sections, and collecting and analyzing sediments for provenance (mineralogical, geochemical, and isotopic methods; Muhs and others, 1996, 1999a; Aleinikoff and others, 1999; Aleinikoff and Muhs, 2010). Historical studies of dune fields are based on archival aerial photography and written accounts. Potential source sediments are sampled and compared with dune sand and loess compositions for inferring paleowinds. Paleosols within loess are studied for inferences about past vegetation.

Research Plan

Several studies associated with this subtask currently (2011) are underway. One study involves testing the suitability of fossil land snails for radiocarbon dating by collecting and analyzing snails from independently dated loess sections in Nebraska and eastern Colorado. Fossil land snails are abundant in loess deposits; developing a reliable technique for dating their shells will provide a valuable method for dating loess sections and potentially other fine-grained terrestrial sediments (Pigati and others, 2010). A second study focuses on provenance of the Wray dune field, eastern Colorado, using geochemical analyses of eolian sand units to test the hypothesis that this dune field is derived from the South Platte River (Muhs and others, 1996; Muhs and others, 1999b). A third focuses on isotopic studies of detrital zircons to determine provenance of the Fort Morgan and Greeley dune fields, eastern Colorado. Current results of this latter work show that although the Fort Morgan dune field is derived from the South Platte River, the Greeley dune field to the north is derived from bedrock sources (Aleinikoff and Muhs, 2010). These results indicate that nonfluvial sources for dunes may be more important than previously thought, and have implications for inferring paleowind direction and for interpreting ties between dune sand and dynamics of the fluvial system.

Work on this subtask as an integrated part of the “Greater Platte River Basin and Northern Plains Geologic Framework Studies” project was made possible by funding from the Global Change Program, and its continuation is dependent on continued support from that program.

Communication Plan

Communication about the results of this study are made through several means: (1) peer-reviewed scientific literature, primarily journal articles and book chapters; (2) oral presentation of results at meetings of national and international scientific organizations and ad hoc, topical conferences; (3) USGS professional papers, fact sheets, and Web sites; and (4) the press, including newspaper articles, magazine articles, and books.

Hydrogeologic Framework Studies

Republican River, Nebraska and Kansas

The GPRB contains some of the most productive agricultural areas in the United States, and is greatly dependent on groundwater for irrigation. The area also is an important ecosystem in the Central Flyway of North America, with whooping cranes and other migratory birds passing through and needing protection of their wildlife habitat. Water resources of the Republican River Basin, used intensively for irrigation as well as for drinking water, recreation, and wildlife habitat, are regulated by an interstate compact between Nebraska, Kansas, and Colorado, and are the subject of litigation between the states over claims of over-appropriation and noncompliance (*http://www.republicanrivercompact.org/; http://www.ksda.gov/interstate_water_issues/content/142)*. Water sustainability in the basin is a major concern, made more acute by the possibility of diminishing water supplies as climate changes.

Geologic Setting

Principal groundwater resources of the central Great Plains are contained within the High Plains aquifer (Weeks and others, 1988; McMahon and others, 2007), which is a composite of several distinct, but incompletely mapped, hydrogeologic units of Tertiary to Quaternary age. It overlies mostly marine Cretaceous sedimentary rocks, which also contain a major, mostly fluvial nonmarine aquifer (Dakota Sandstone) in central Nebraska and Kansas. The lowermost hydrogeologic unit in the High Plains aquifer is the Miocene Ogallala Formation (Ludvigson and others, 2009; Macfarlane, 2009), a continental sand and gravel aquifer that has been critically overdrawn in much of its southern extent, from Kansas to Oklahoma and Texas (Weeks and others, 1988). The Ogallala aquifer provides much of the base flow within the Republican River watershed because headwaters of the river are on the High Plains of eastern Colorado and Kansas; in contrast to the Platte River, the Republican River is not connected to any montane recharge. Overlying the Ogallala are Pliocene (including the Broadwater Formation in central Nebraska) and Quaternary alluvial sediments that have variable aquifer properties (Condon, 2005; Macfarlane, 2009), but these sediments have not been uniformly mapped in Nebraska and Kansas. Commonly, these units are combined and referred to as "principal aquifer" or undivided High Plains aquifer. In the central reach of the Republican River of Nebraska, the saturated thickness of the High Plains aquifer is generally less than 300 feet (91 m; McMahon and others, 2007), and locally it may be separated from much thicker parts of the aquifer north of the Platte by outcropping bedrock (for example, Miller and others, 1964; Dreeszen and others, 1973). Interestingly, it has been proposed that in this central reach of the Republican River, there may be early and middle Quaternary Platte River paleovalleys buried beneath younger sediments (for example, Swinehart and others, 1994), which may act as groundwater conduits or create important local aquifers.

Mapping and Research Plan

Hydrogeologic framework studies of the Republican River watershed focus on (1) compiling a new generation of surface and subsurface geologic maps in hydrologically significant parts of the Republican River watershed in Nebraska and Kansas, and (2) relating bedrock and surficial deposits to the Greater Platte River watershed and its ecosystems to better understand surface water-groundwater interactions in the aquifer. This work is being developed in collaboration with the USGS NEWSC and the UNL CSD, and will be coordinated with the Kansas Geological Survey (KGS), USGS Kansas Water Science Center (KSWSC), and local NRDs in Nebraska.

Geologic mapping, at a scale of 1:100,000 or smaller, will build upon available published mapping, including: 1:1,000,000-scale regional Quaternary Atlas maps of the Platte River (Swinehart and others, 1994) and Wichita (Denne and others, 1993) quadrangles; 1:250,000-scale bedrock geologic maps of the McCook (Eversoll and others, 1988) and Grand Island (Dreeszen and others, 1973) quadrangles, which show only thickness of Quaternary deposits; 1:50,000-scale geologic maps of Phillips (Johnson and Arbogast, 1993) and Norton Counties, Kansas (in progress; Appendix); and older but good quality, 1:48,000-scale geologic mapping for Franklin, Nuckolls, and Webster counties, Nebraska (Miller and others, 1964). Quaternary tephra samples from Kansas and Nebraska, housed at the USGS in Denver, have been studied and part of this work is published (Izett and Wilcox, 1982), but other samples could yield additional data if studied with modern methods; volcanic ash beds are key time-stratigraphic markers useful for dating sedimentary deposits and correlating stratigraphic sections in the map area.

New digital geologic mapping of selected areas within the Republican River watershed in Nebraska and Kansas will focus on better defining geologic deposits in the surface and subsurface that affect groundwater-surface water interactions and flow. Specifically, Quaternary fluvial and eolian deposits will be mapped from the surface into the subsurface, and Cretaceous sedimentary bedrock and Miocene Ogallala Formation will be mapped from lower contacts upward; this strategy will allow definition of the unmapped Pliocene (5–2.6 Ma) and pre-Wisconsin (2.6 Ma–>130 ka) alluvial deposits that contain (together with the Ogallala Formation) the principal groundwater resources of the Republican River watershed. Souders (2000), Diffendal and others (2008), and Johnson and Arbogast (1993) provide good examples of modern geologic maps that combine this type of surface and subsurface geologic data. Compilation of existing geologic mapping along the Republican River will be the first stage of this work. Later, more detailed mapping will focus on the highest priority areas of the Republican River and adjoining Platte River. The KGS recently completed new mapping of the Ogallala part of the High Plains aquifer in western Kansas that contours the Ogallala aquifer thickness and elevation (Macfarlane and Wilson, 2006). Similar data exist for the Republican River watershed in Nebraska, but have not been evaluated or published. We plan to work on these data sets in collaboration with the USGS NEWSC, UNL CSD, KGS, and USGS KSWSC. Our mapping will provide a fundamental data set for groundwater models of this part of the High Plains aquifer.

Communication Plan

This hydrogeologic framework task is being done in collaboration and/or coordinated with a number of other scientific entities (USGS NEWSC, UNL CSD, several Nebraska NRDs, KGS, and USGS KSWSC), and the task leader will communicate frequently with them about research activities. Project results will be communicated through reports of scientific investigations, which may include: airborne, surface, and/or subsurface geophysics; Quaternary tephrochronology; and maps and cross-sections relating bedrock and surficial geology to High Plains aquifer hydrogeology.

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Appendix—Geologic Map Coverage Index

An index of geologic mapping in the GPRB was compiled as a resource for evaluating current status, to help identify data gaps and areas where new digital geologic mapping would benefit ecosystem and climate change research. Mapped areas shown on figure 2 correspond to the Geologic Map Publications section of this report and are intended to illustrate locations for which geologic quadrangle mapping is available. The figure is not intended to reflect data gaps, which involve additional factors such as map scale, map age, research focus, and technology available at the time of mapping and research. For example, not all of the maps listed are of surface geology; particularly for Nebraska, some focus on subsurface bedrock geology and do not map overlying surficial deposits (Burchett and others, 1972, 1975, 1988; Dreeszen and others, 1973; Eversoll and others, 1988; Souders, 2000). In the Republican River drainage, much of the published mapping was done in the 1950s and lacks a topographic base, although new mapping is in progress in a few of the counties (fig. 2).

Recent geologic mapping efforts in the South Platte drainage, published since 2000, have focused on the mountainous headwaters and the urban corridor along the Colorado Front Range (see the Geologic Map Publications section of this report: Widmann and Miersemann, 2001; Thorson, 2003, 2004a, 2004b, 2005a, 2005b, 2006, 2007; Thorson and Madole, 2003; Thorson and Himmelreich, 2004; Widmann and others, 2004, 2005, 2006; Morgan and others, 2004, 2005; Kirkham and others, 2006, 2007; Temple and others, 2007, 2008; Kellogg and others, 2008; Ruleman and Bohannon, 2008; Workman, 2008; Cole and Braddock, 2009; Morgan, 2009), and late Quaternary wind-deposited sand in eastern Colorado (Madole and others, 2005; not shown on fig. 2). Geologic mapping for much of the GPRB in Wyoming has recently been published at a scale of 1:100,000.

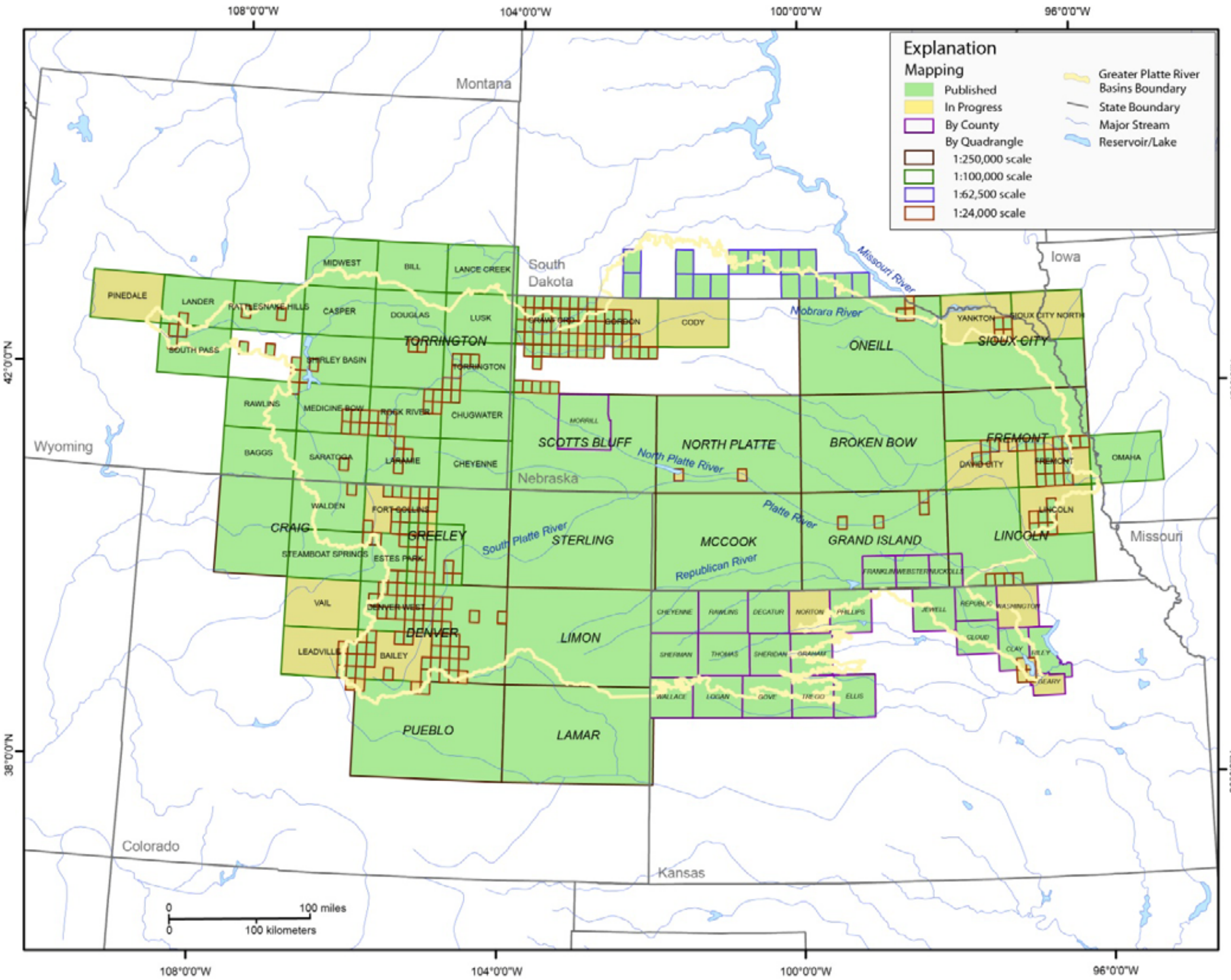

Figure 2. Index of geologic map coverage corresponding to publications listed below. Only 1:250,000- and larger-scale quadrangle and county maps shown. White areas within the Greater Platte River Basins boundary are areas for which no geologic map coverage was found. Data on new mapping that has either been completed but not yet published, or that is in progress were gathered from State Geological Survey, U.S. Geological Survey National Geologic Map Database, and National Cooperative Geologic Mapping Program websites. Geographic Information System coverage of Greater Platte River Basins boundary provided by Nathan J. Schaepe and Ronald B. Zelt at the U.S. Geological Survey Nebraska Water Science Center.

Geologic Map Publications

To aid the reader in identifying geologic map coverage that might be of interest to them, the names of quadrangles, or in some cases counties, states, or geographic areas covered by the geologic maps, are highlighted in bold font.

Multi-State

Stoesser, D.B., Green, G.N., Morath, L.C., Heran, W.D., Wilson, A.B., Moore, D.W., and Van Gosen, B.S., 2005, Preliminary integrated geologic map databases for the United States; central states; Montana, **Wyoming, Colorado**, New Mexico, **Kansas**, Oklahoma, Texas, Missouri, Arkansas, and Louisiana: U. S. Geological Survey Open-File Report OF 2005-1351.

1:5,000,000

Soller, D.R., Reheis, M.C., Garrity, C.P., and Van Sistine, D.R., 2009, Map database for surficial materials in the conterminous United States: U.S. Geological Survey Data Series 425, scale 1:5,000,000 [*http://pubs. usgs. gov/ds/425/*].

1:1,000,000

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Bailey
Fort Collins
Leadville (east half)
Vail (east half)

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In progress

Antero Reservoir
Climax
Divide
Eastonville
Marmot Peak

Other

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Kansas

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In progress

Geary
Norton
Washington

1:24,000 (in progress)

Milford
Milford Dam
Upland
Wakefield

Other

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Yankton

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