Siliciclastic Sedimentation in Paleocaves of the Pekisko Formation, Twining Field*

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Abstract

Karst landforms developed on the post-Mississippian surface in the Twining area are expressed as topographic irregularities interpreted as buried hills, dolines, and collapsed valleys. The surface is composite and developed over a period of time spanning about 140 my culminating in burial of the karst terrain in the Early Cretaceous. Speleogenesis of underlying carbonates is manifest as paleocaves outlined by unconformities that separate the host Pekisko Formation (Tournaisian) from younger siliciclastic sediment fills.

Sediment that fills the paleocaves belongs to three different facies. *Diamictite* facies is characterized by poorly sorted sediment ranging from boulders through pebbles and sand supported in fine-grained clayey matrix. *Sandstone* facies is comprised of sands and pebbly sands with current-induced structures and crudely developed soft-sediment deformation. *Shale* facies includes maroon, grey-green, and gleyed mudstones with well-developed slickensides. Paleocave fills are interpreted to have been emplaced by allogenic groundwater recharge from sinking streams.

Each of the paleocave facies is interpreted in terms of depositional environments known from modern caves. Diamicton develops under conditions of extreme sedimentation when landslides or debris flows enter a cave system. Sand is deposited in fluvial channels with stratification the consequence of the local flow regime; soft- sediment deformation of the sands probably occurs during floods when the sediment mass is sheared through confined passages. Mud represents slack-water deposition in ephemerally submerged reaches of caves. Wetting and drying of mud leads to maroon and green coloration along with the development of slickensides, and is analogous to sedimentation and pedogenesis on floodplains.

Introduction

Although paleocaves have long been associated with regional unconformities, surprisingly few studies have documented the nature of the siliciclastic sediment that fills some paleocaves. Such is the case with the Pekisko Formation that subcrops over an expanse of several hundreds of kilometres in central Alberta. Paleocaves (of dimensions that a paleogeologist may have been able to crawl into) can be identified from logs of wells drilled along the Pekisko subcrop belt, however, few cave deposits have been cored. An exception is the Twining area where Reid (1999) documented cave deposits in several wells. The relatively dense well spacing and unusual concentration of cored wells renders Twining amenable for the study of paleocaves and paleokarst.

Regional Setting

The Phanerozoic succession beneath the plains of southern Alberta is a southwest-dipping wedge of sediments comprised of three parts: (i) A succession of Cambrian to Mississippian sequences comprised of carbonates, evaporites, and siliciclastics deposited on a cratonic platform and separated by regional unconformities. (ii) A Late Mississippian to Early Jurassic zone of unconformities (Norris and Bally, 1972). Sedimentary rocks of this age are unconformity-bounded formations generally preserved only in areas of greater subsidence to the west or northwest of Twining. (iii) Middle Jurassic to Early Tertiary sandstones and shales deposited in a foreland basin.

The pre-Jurassic surface in western Canada formed a vast paleoplain (Martin, 1966) across which topography was dominated by ridges of resistant carbonate rock forming cuestas separated by swales or mesas in less competent fine-grained siliciclastics and carbonates. One of these cuestas is supported by the Pekisko and Shunda Formations of Tournaisian age.

At Twining (and elsewhere in southern Alberta) this paleoplain has been further sculptured by erosion during the Late Jurassic/Early Cretaceous. Mississippian carbonates (Pekisko and Shunda Formations) are overlain by Lower Cretaceous siliciclastics (Deville Formation, Mannville Group). The time gap separating the carbonate and siliciclastic rocks spans some 140 million years. Given that the karst cycle can mature in a few million years, it is not surprising that karst forms have developed on underlying carbonate rocks.

Stratigraphy

Pekisko Formation is dominantly well-cemented grey crinoid grainstone-packstone-wackestones successions of variable low porosity. Locally, grainstone shoals up to about 10 m thick are present. In many wells, low-radiation gamma ray profiles of the Pekisko Formation are punctuated by thin radiation spikes representing fissures and cavities of centimetre- to decimetre-dimensions filled with shale and sandstone. Sandstone and shale-filled paleocaves of metre-plus dimensions are sparingly present.

Shunda Formation is comprised of green argillaceous dolostones, lime-mudstones, and fine grained pellet grainstones, locally with breccias and shale-filled cavities. Porosity and permeability are very low. Gamma log profiles vary from blocky to serrated; the serrated signature records variable argillaceous components of the formation and possibly the presence of shale-filled cavities, although the two cannot be distinguished on logs.

Mannville Group is comprised of variable quartz and chert-rich sandstones and grey to green shales. The Deville Formation at the base of the Mannville Group is variable green and red gleyed slickensided shales representing paleosols at the base of the Mannville Group. The age of the Deville is uncertain but the formation is interpreted to represent residual deposits from weathering at the Late Jurassic/Early Cretaceous unconformity (Poulton et al. 1994).

Karst Paleotopography

Paleotopography of the Mississippian subcrop is inferred from a 3D projection of an isopach map of the post-Mississippian surface (Shunda and Pekisko Formations) to the top of the Banff Formation, using the Banff Formation as a datum (Figure 1). Regional dip of the Banff-Pekisko surface of a fraction of a degree to the southwest during the Early Cretaceous is rendered flat in this projection. The erosional surface portrayed is a composite surface that was variously modified by a series of superimposed unconformities. Paleotopography on the surface of the Banff Formation, where the Pekisko Formation has been removed by erosion, is artificially rendered as a low flat surface because a zero value has been assigned to the interval thickness.

The diagram portrays many of the expected features of an eroded carbonate subcrop edge with karst landforms interpreted as isolated hills, valleys, and dolines. Isolated hills are represented by irregular-shaped highs, one in the centre, and another in the southeastern corner of the map. Valleys are irregular elongate reaches several kilometres long and up to 80 metres deep, which probably represent collapsed caves. Closed and partly closed depressions a few hundred metres across and commonly defined by only one or two wells are interpreted as dolines (sinkholes). The sub-circular form is an artifact of the contouring; however, in areas where proprietary 3D seismic has been obtained, a rough sub-circular form of depressions on the Mississippian surface is manifest.

Paleocaves

Paleocaves are recognized from logs as lithologic discontinuities with irregular boundaries: sandstone/shale versus limestone. Recognition of paleocaves from vertical boreholes that randomly intersect paleocave passages requires some further extension of the imagination; a measured vertical thickness must be perceived as part of a tortuous three-dimensional passage that was sufficiently wide and continuous to have formed a cave. Among the 296 wells that penetrate the Pekisko Formation in the study area (Figure 1) 5 encountered paleocaves. In considering the form and occurrence of paleocaves it should be recalled that these features are observed only in cores and wireline logs from boreholes. Not only is perception limited to a core sample 7-10 cm wide, but paleocave deposits are commonly destroyed in the coring process as the bit passes from the relatively competent carbonate lithology of the host formation into much less competent sandstones and shales.

Facies

Three cores illustrate the range of facies of paleocave deposits: 10-03-032-24W4, 13-03-032- 24W4 and 08-25-032-25W4 (Figure 1). Log signatures and interpreted stratigraphic relationships for 10-03-032-24W4 and 13-03-032-24W4 are given in Figure 2.

Diamictite facies is characterized by poorly sorted sediment ranging from boulders through pebbles and sand, supported in fine-grained clayey matrix. Boulders and pebbles are silicified carbonate rock fragments and chert. Poor sorting and lack of any organized sediment structures suggest that diamicton was emplaced by a debris flow mechanism. Gillenson (1986) has described diamicton from landslides where the entrained sediment entered a cave and was deposited in constricted passages. Diamicton sediments likely follow the stream course in the cave but are not confined to it.

Sandstone facies is comprised largely of medium to coarse-grained sand. Sand-supported pebbles and clusters of pebbles are present locally at the base of irregular scours. The sand is usually moderately to poorly sorted, commonly with a clay matrix. Cross-stratification and soft-sediment deformed cross stratification is present locally. Laminae tend to be diffuse as the contacts between laminae are gradational. Sedimentary structures are interpreted as current-laminated structures from fluid gravity flows that subsequently have been modified by soft-sediment deformation. That is, the sediment mass has moved as a whole following deposition of individual bed-sets. A likely mechanism for movement is frictional shear of the sediment mass by an overlying flow. Although not exclusive to cave deposits, the confines of a cave passage enhance the likelihood of shear through increased pore pressure.

Shale facies includes maroon, grey-green, and gleyed mudstones with well-developed slickensides. Superficially the slickensides might be interpreted as a form of tectonic slickensides caused by compaction and adjustment of the fine-grained sediment fill. However, the lack of systematic orientation of the slickensides and their association with red/drab gleyed sediments suggests they are similar to pedogenic slickensides. Wetting and drying of smectitic soil horizons produces pedogenic slickenside in paleosols. Cave sediments also undergo periodic wetting and drying as is shown by shrinkage cracks on mud banks in many caves.

Discussion

At Twining it is impossible to directly determine the origin of the caves as neither the morphology of the caves can be observed, nor are there speleothems from which to deduce the paragenesis of geofluids. Prolonged exposure of the Mississippian formations (up to 140 my), karst land forms on the paleoweathering surface formed over these formations, and fill of caves by fluvial sediments are an association that points towards a vadose origin, or at least significant modification of paleocaves by near-surface meteoric processes.

All paleocaves recognized from core and/or geophysical logs have been filled with siliciclastic sediments to the limit of the roofs. Bit-drops, indicators of fluid-filled space in the subsurface, have not been recorded from Twining wells. Either sediment filled these caves everywhere to the roof, or the roofs have subsequently collapsed until they rest on the sediment pile. Some roof adjustment is required even in filled caves to account for compaction of shales, however, cores of roofs above caves generally preserve the sub-horizontal bedding characteristic of the Pekisko Formation: none have obviously rotated bedding that might indicate roof collapse.

Sedimentary structures reflect episodic transport of sediment by confined flows in irregular passages. Cross-stratified sandstone indicates transportation and deposition occurred in the upper phase of the lower flow regime. Slumping and soft-sediment deformation structures are attributed to sedimentation in irregular steep passages that became overloaded. Interbedding of sandstone and shale is interpreted to reflect changes in velocity between flood cycles. Shale represents mudstones deposited in slack water stranded by waning floods. Thus, the signature of the sediments that fill the paleocaves is a fluvial signature, in common in many modern caves that support sinking streams (Bosch and White, 2004). Point bars that develop within caves are similar in form to those of streams with a vertical succession of sedimentary structures indicating deposition under successively lower flow regimes. Shales that accumulated in lateral passages or at levels stranded after floods are analogous to floodplain deposits. Infiltrated sediments that trickled through fissures not connected with the sinking stream can be envisaged as streamlets that enter the backs of swamps.

The age of Twining cave-fill deposits cannot be directly determined: samples of shales have failed to yield any useful palynomorphs. The clay mineralogy of cave-fill sediments and shales from the overlying Mannville Group is similar suggesting a common Late Jurassic/Early Cretaceous age. Similar deductions have been reached elsewhere along the Pekisko Formation subcrop (Hopkins, 2004, his Figure 13). Given the very broad span of time represented by the unconformity above these carbonates, however, it seems likely that older paleokarst deposits may be eventually dated.

Speleogenesis and cave filling was terminated in the Early Cretaceous after which the basin was filled with several kilometres of siliciclastic sediments. Unconformities within the succeeding fill, including the present erosion surface, never again cut deeply to exposure the Pekisko subcrop in southern Alberta.

Summary and Conclusions

1. Siliciclastic sediment-filled paleocaves are present along the subcrop edge in the Pekisko Formation throughout the Twining oil field.
2. The caves formed somewhere within the period of 140 my between deposition of the Pekisko Formation (Tournaisian) and the deposition of overlying Lower Cretaceous sediments.
3. Siliciclastic sedimentation took place from sinking streams that entered caves during a final period of vadose modification of the caves.
4. Diamictite facies represents rapidly emplaced sand and pebbly sand that entered the cave as debris flows; sandstone facies formed from lower flow regime fluid-gravity flows; shale facies are fine-grained sediments that settled after floods.
5. Speleogenesis and cave-filling were effectively terminated in the Early Cretaceous when the caves were buried beneath a subsiding foreland basin.

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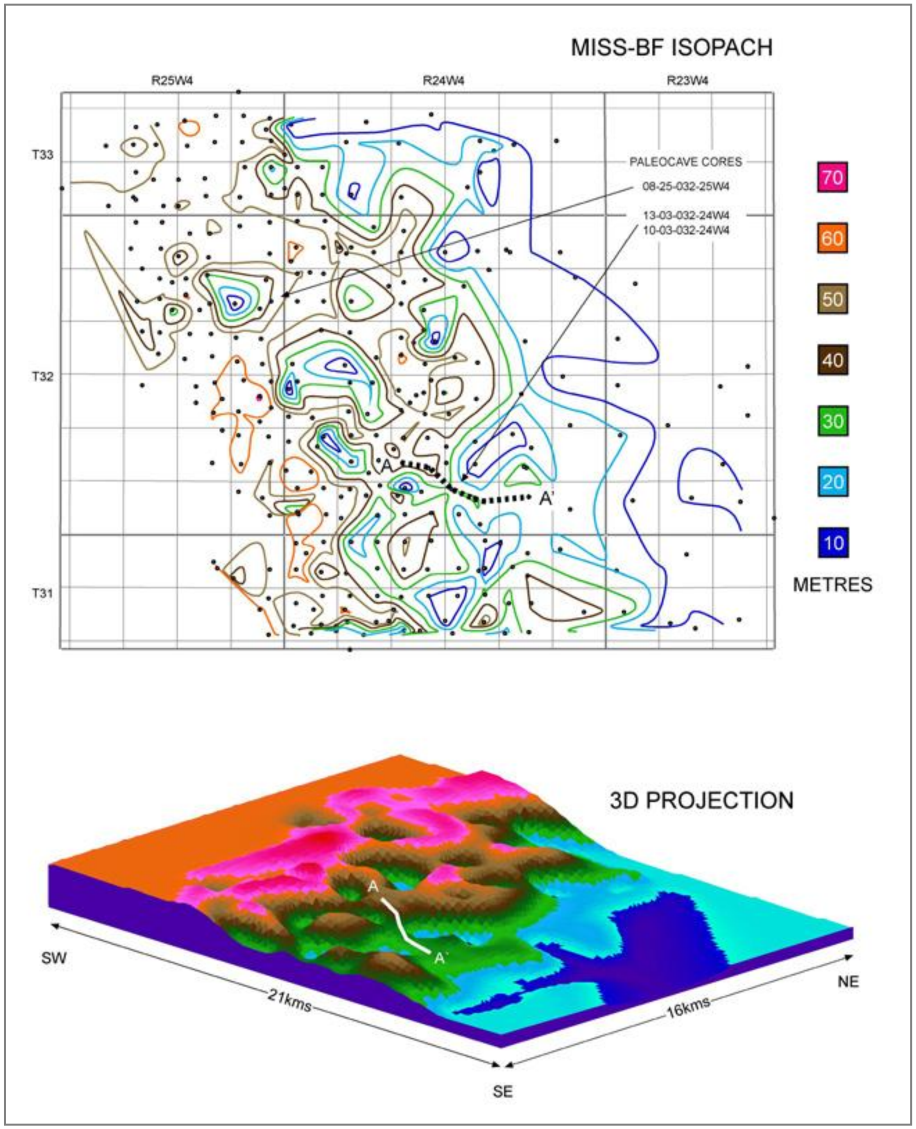

Figure 1. Paleotopography of the post-Mississippian surface in the centre of Twining Field. AA' is line of section in Figure 2. The 3D projection is derived from the Mississippian to Banff isopach flattened on the top of the Banff Formation. Orange shading to the west marks the limit of isopach data. Data in part from Reid (1999) and Nimmo (2004).

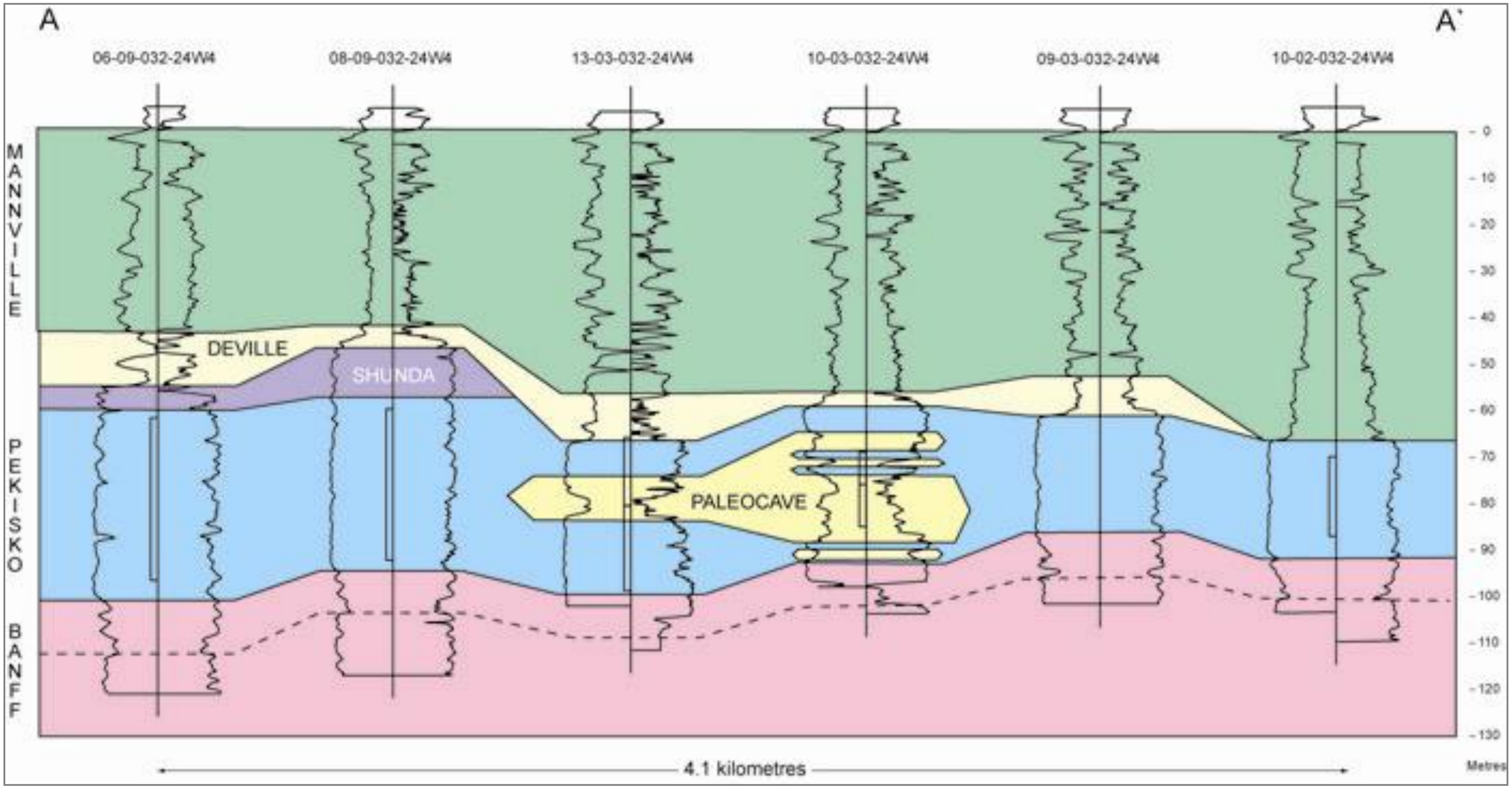

Figure 2. Cross section AA (see location on Figure 1) with interpreted stratigraphic relationships and cores from paleocaves, 10-03-032-24W4 and 13-03-032-24W4. Well logs are gamma (left) and sonic (right). Datum is a prominent coal seam within the Mannville Group. Dashed line is the base of a correlative shale horizon near the top of the Banff Formation.