Thrust-top basin formation along a suture zone, Cantwell basin, Alaska Range: Implications for development of the Denali fault system

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ABSTRACT

The Cantwell Formation consists of a lower sedimentary sequence as much as 4000 m thick and an upper volcanic sequence with a maximum thickness of 3750 m that was deposited in the Cantwell basin, south-central Alaska. Previous to this study, the Cantwell basin was interpreted as a Paleogene, nonmarine (mainly fluvial), pull-apart basin that formed in response to dextral, strike-slip displacement on the Denali fault system. This study proposes that the Cantwell basin formed as part of the Mesozoic accretionary phase of deformation, prior to the development of the Cenozoic postaccretionary Denali fault system. Our reinterpretation is based on several new lines of data.

(1) Age. New data based on palynologic analyses of 135 fine-grained samples indicate that the lower Cantwell Formation was deposited during the late Campanian and early Maastrichtian. On the basis of previous regional tectonic studies and this new age constraint, the formation of the Cantwell basin was coeval with regional Late Cretaceous shortening associated with accretionary tectonics in southern Alaska.

(2) Depositional systems. Our analysis of the Cantwell Formation demonstrates that sedimentation occurred mainly in stream-dominated alluvial fan, axial braided stream, and lacustrine settings. These depositional systems were strongly influenced by a southward dipping, asymmetric basin floor. The presence of abundant terrestrially derived organic material, together with palynological assemblages that include marine dinoflagellates and the associated presence of oncolites, may be suggestive of a time of marginal marine influence during the deposition of the upper part of the lower Cantwell Formation. The late Campanian to early Maastrichtian timing of this possible marine influence is within the range of the Bearpaw transgressive event of the Cordilleran foreland basin and allows for regional stratigraphic correlation of the Cantwell basin with other sedimentary basins in northwestern North America.

(3) Structural controls on basin formation. Mapping of intraformational angular unconformities and progressively tilted strata along the southern margin of the Cantwell basin provides direct evidence that thrust fault deformation and lower Cantwell Formation sedimentation were synchronous. Distinctive Cantwell Formation conglomerate clasts derived from the uplifted hanging walls of nearby thrust sheets adjacent to the southern basin margin also support a syndepositional thrusting interpretation. Provenance data and the concentration of proximal alluvial fan deposits along the northwestern basin margin adjacent to the Hines Creek fault indicate that it, too, was active during deposition of the Cantwell Formation.

On the basis of the new data, the Cantwell basin is interpreted to have formed as a thrust-top basin (i.e., piggyback basin) along the Late Cretaceous suture zone between the accreting Wrangellia composite terrane and the North American continental margin. In contrast to previous studies, this reinterpretation of the formation of the Cantwell basin implies that the lower Cantwell Formation is not a synorogenic deposit directly associated with strike-slip displacement along the Denali fault system. Therefore, the Cantwell basin cannot be used to constrain the timing for the early development of the Denali fault system.

INTRODUCTION

The Cantwell Formation is presently exposed in a 45-km-wide and 135-km-long, east-west-trending outcrop belt referred to here as the Cantwell basin (Fig. 1A). The basin is located approximately between the Hines Creek fault to the north and the McKinley fault to the south within the central Alaska Range (Fig. 1B). The McKinley fault is part of the 2000-km-long Denali fault system that extends from British Columbia to western Alaska (Fig. 1A). The Cantwell Formation consists of two distinct lithologic units, an upper volcanic unit and a lower sedimentary unit (Wolfe and Wahrhaftig, 1970). The sedimentary unit of the Cantwell Formation, referred to here as the lower Cantwell Formation, consists of a thick sequence of conglomerate, sandstone, siltstone, mudstone, coal, and minor volcanic rocks (Wolfe and Wahrhaftig, 1970; Hickman, 1974; Sherwood, 1979). Although thickness varies throughout the basin, the maximum preserved thickness of the lower Cantwell Formation is 4000 m (Hickman et al., 1990). The upper volcanic unit, informally referred to as the Teklanika formation, consists of intercalated andesite, rhyolite, and basalt flows, subordinate pyroclastic and intrusive rocks, and minor sedimentary rocks (Gilbert et al., 1976). The maximum preserved thickness of the volcanic sequence is 3750 m (Gilbert et al., 1976). Although usually conformable, the contact between the upper volcanic unit and the underlying sedimentary unit is an angular unconformity at some locations (Gilbert et al., 1976; Csejty et al., 1986), especially along the southern basin margin (Ridgway et al., 1995b). The Cantwell Formation unconformably overlies a complex assemblage of Precambrian (?) to Cretaceous rocks that may represent several tectonostratigraphic terranes (Csejty et al., 1986; Jones et al., 1983, 1987).

Field mapping (Eldridge, 1900; Brooks and Prindle, 1911; Capps, 1940; Reed, 1961; Wahrhaftig, 1970a, 1970b, 1970c, 1970d; Decker, 1975; Gilbert and Redman, 1975; Hickman and Craddock, 1976; Sherwood and Craddock, 1979; Csejty et al., 1986, 1992), stratigraphic and paleobotanical analyses (Eldridge, 1900; Wolfe and Wahrhaftig, 1970; McLean and Stanley, 1992), and structural studies (Hickman, 1974; Sher-
Figure 1. (A) Map of Alaska showing the Denali fault system (bold black line) and the location of the Cantwell basin (black area). (B) Geologic map of the Cantwell basin in south-central Alaska. The gray areas represent exposures of the lower Cantwell Formation, a predominantly sedimentary unit. The hashed areas represent exposures of the upper Cantwell Formation, a predominantly volcanic unit. Abbreviations mark locations of measured stratigraphic sections in the lower Cantwell Formation discussed in text. Geology from Reed (1961), Csejtey et al. (1992), Hickman and Craddock (1976), Sherwood and Craddock (1979), and this study.

Several new lines of data from this study indicate that the Cantwell basin formed in response to Late Cretaceous thrusting associated with suturing of the Wrangellia composite terrane to southern Alaska (Plafker et al., 1989) and is not directly related to Cenozoic strike-slip displacement on the Denali fault system. Paleontological analyses indicate that the lower Cantwell Formation was deposited during the late Campanian and early Maastrichtian of the Late Cretaceous. Reconstruction of depositional systems demonstrates that sedimentation was predominantly by stream-dominated (“wet”) aluvial fan, axial braided stream, and lacustrine environments within an asymmetric basin. The presence of marine dinoflagellates in association with oncolitic limestones is taken to suggest a marine incursion within the upper part of the lower Cantwell Formation. Mapping of intraformational unconformities and progressively tilted strata along with compositional data indicate that sedimentation was synchronous with thrust fault deformation in the Cantwell basin. In light of the new data, the Cantwell basin is interpreted as having formed on a series of active thrust faults as a thrust-top basin (i.e., piggyback basin). We will discuss the evidence for each of these new interpretations in the following sections.

AGE

The age of the lower Cantwell Formation, based on interpretations of fossil plant leaf biostratigraphy, has been controversial and unclear. The formation was originally interpreted as Eocene (Moffitt, 1915), but later assigned to the Cretaceous (Chaney, 1937). Imlay and Reeside
(1954) placed the Cantwell Formation in the Albian of the Early Cretaceous. Most recently, the lower Cantwell Formation was interpreted as Palaeocene, based on reexamination of Chaney's original fossil collection and analysis of additional plant fossil localities (Wolfe and Wahrhaftig, 1970; J. A. Wolfe in Hickman, 1974).


Nichols and Sweet (1993) proposed a series of palynologically based datums applicable to the zonation of Late Cretaceous strata throughout midcontinental North America. The Santonian-Campanian boundary is approximated by the *Aquilapolipollenites* datum marked by the first conspicuous presence of *A*. sp. Given the number of species of *Aquilapolipollenites* in the lower Cantwell Formation, its age is certainly younger than Santonian. The Cantonian-Maastrichtian boundary is approximated by the *Wodehouseia-Kurtzipites* datum marked by the first occurrences of either or both of the name-bearing genera. Of these two genera, only *Kurtzipites* occurs in the upper part of the lower Cantwell Formation (measured section PC1 in Fig. 1B). The absence of these genera from all but the PC1 section constrains the age of much of the lower Cantwell Formation to the Campanian. As *Kurtzipites* occurs, albeit rarely, in section PC1, it is considered to be of Maastrichtian age. The beginning of the late Maastrichtian is identified by the *Wodehouseia spinata-Manciocorpus vanampaoae* datum (Nichols and Sweet, 1993). No species characteristic of this datum, or of the late Maastrichtian, was recorded from the lower Cantwell Formation. This, and the fact that most species of *Aquilapolipollenites* do not range into the Paleocene (above the K-T boundary extinction event), precludes the sampled portion of the lower Cantwell Formation from being younger than early Maastrichtian in age. Analyzed samples from three of our measured sections (PC1, DM1, and DC1 on Fig. 1B) were collected within several meters of the base of the upper Cantwell Formation volcanic rocks, thereby ensuring that we have a complete record of the uppermost lower Cantwell Formation. Further constraints on the age of the lower Cantwell Formation are gained by the presence of *Cranwellia*, whose earliest record is taken to identify the beginning of the late Campanian *Cranwellia* Suite of Norris et al. (1975). Additionally, the presence of *Azonia sufflata* (occurs in DM1, JC1, and possibly FM1 sections on Fig. 1B), a species found otherwise in the Campanian of Alaska (Wiggins, 1976), implies that at least some of the lower Cantwell Formation is no younger than Campanian. The age of the lower Cantwell Formation is, therefore, determined to span the late Campanian and early Maastrichtian based on the recovered species. The Paleocene age previously interpreted from macrofossils (Wolfe and Wahrhaftig, 1970) is based on a relatively restricted plant assemblage. The age implications of this plant assemblage need to be re-examined in light of our results.

The new palynological data are in general agreement with previously conflicting Late Cretaceous K-Ar age determinations (71.9 ± 2.7 Ma, biotite; 78.7 ± 3.6 Ma, biotite) obtained from two granitic stocks that intrude the lower Cantwell Formation. These were discounted in favor of the Paleocene fossil ages (Fig. 4) (Hickman, 1974; Hickman and Craddock, 1976; Sherwood and Craddock, 1979) and with isotopic age determinations (50.9 ± 2.2 Ma, whole rock; 56.6 ± 2.4 Ma, whole rock; 58.7 ± 3.5 Ma, plagioclase; 60.4 ± 3.1 Ma, whole rock; 61.0 ± 2.8 Ma, whole rock; and 64.6 ± 3.4 Ma, hornblende) from the overlying volcanic rocks of the upper Cantwell Formation (Fig. 4) (Bultman, 1972; Sherwood, 1973; Hickman, 1974; Gilbert et al., 1976). All the cited K-Ar age determinations were recalculated using the constants of Steiger and Jäger (1977) (from Csejtey et al., 1992).

**DEPOSITIONAL SYSTEMS**

The Cantwell basin was filled by three principal types of depositional systems: (1) southward-flowing, stream-dominated alluvial-fan systems; (2) eastward-flowing, axial sandy braided stream systems; and (3) lacustrine systems concentrated in the south-central part of the basin (Fig. 5). Measured stratigraphic sections, lithofacies analysis, maximum particle-size data, and paleocurrent analysis indicate that each of the depositional systems was influenced by a southward-tilted basin floor (Fig. 5). We have also documented a marginal marine influence in the upper part of the lower Cantwell Formation. Facies associations for each of the depositional systems documented in the lower Cantwell basin are described below.

**Stream-Dominated Alluvial Fan Systems**

Three common facies associations have been documented for alluvial-fan deposits in the Cantwell basin. A description of each facies association will be presented and then a general interpretation for the three facies associations will be discussed.

**Facies Association 1.** The Cantwell Formation along the northwestern margin of the Cantwell basin is characterized by clast-supported, boulder and cobble conglomerate (Fig. 6A). Subrounded to rounded clasts, polymodal grain-size distribution (very coarse sand to boulder) and α(1)β(i) imbrication (Harms et al., 1982) are common features in facies association 1. Average maximum particle size in facies association 1 is 11 cm (Fig. 7A), but clasts as much as 34 cm in diameter are present. The measured section at Mount Sheldon (MS1) (Figs. 5 and 8) is representative of facies association 1. This section is characterized by amalgamated, 10–30-m-thick conglomeratic units that form 50–60-m-thick packages that are laterally continuous for hundreds of meters. Internally, lenticular channels can be defined within the conglomerate packages. Separating the thick conglomerate packages are laterally continuous, 10–30-m-thick units of mudstone and coal (Fig. 8). Mudstone lithofacies are thinly bedded, contain abundant plant fragments (with in situ tree trunks as much as 2.4 m in height and exquisitely preserved tree leaves), and locally contain burrows. The best developed coal seams in the Cantwell basin occur in facies association 1. The thickest recorded coal seam is 1.75 m.

Facies association 1 is best developed proximal to the Hines Creek fault, which forms the northern margin of the Cantwell basin (Figs. 1B and 5). Paleocurrent indicators along the northern basin margin document south-to-southeast paleoflow (Fig. 7B). This facies association also occurs locally along the southern basin margin adjacent to bordering thrust faults (Fig. 5A).

**Facies Association 2.** Facies association 2 is characterized by upward fining sequences that have a lower, 4–6-m-thick, pebble-to-cobble conglomerate unit which grades upward into massive sandstone that is, in turn, overlain by mudstone (Fig. 6B). The upward fining sequences have sharp erosional lower contacts and are contained within lenticular units that are 200–500 m wide. Conglomerate lithofacies are clast supported, well sorted, contain rounded clasts, and have well-developed α(1)β(i) imbrication. Facies association 2 is well exposed at the Polychrome Mountain measured section (PC1) (Figs. 5 and 8). At the PC1 measured section, the average
Figure 2. Photomicrographs of selected spore and pollen taxa that are representative of the assemblages recovered from the lower Cantwell Formation, Cantwell basin. All figures ×850. Additional detailed information for each specimen shown can be found in the permanent records at the Geological Survey of Canada under the listed GSC type number. (A) Distaltriangulisporites sp., GSC 112740; (B) Hazaria sp., GSC 112741; (C) Equisetosporites sp., GSC 112742; (D) Ginkgo-type pollen, GSC 112743; (E) Pesavis parva Kalugutkar and Sweet, GSC 112744; (F) Leptolepidites sp., GSC 112745; (G) Cyathidites minor Couper, GSC 112746; (H) Aquilapollenites reticulatus (Mchedlishvili) Tschudy and Leopold, GSC 112747; (I) A. paralleus Tschudy, GSC 112748; (J, K) A. sp. cf. A. ceriocorpus Srivastava; (J) GSC 112749; (K) GSC 112750; (L) A. trialatus Rouse, GSC 112751; (M) A. drumhellerensis Srivastava, GSC 112752; (N) A. sp., GSC 112753; (O, P) A. quadrilobus Rouse; (O) GSC 112754; (P) GSC 112755; (Q) A. papilionis Srivastava, GSC 112756; (R) A. aptus Srivastava, GSC 112757; (S) A. contiguus Tschudy, GSC 112758.
Figure 3. Photomicrographs of selected angiosperm pollen and dinoflagellate taxa that are representative of the assemblages recovered from the lower Cantwell Formation, Cantwell basin. All figures ×800. Additional detailed information for each specimen can be found in the permanent records at the Geological Survey of Canada under the listed GSC type number. (A) Aquapollenites scabridus Tschudy, GSC 112759; (B) A. turbidus Tschudy and Leopold, GSC 112760; (C, D) Fibulapollis mirificus (Chlonova) Chlonova; (C) GSC 112761; (D) GSC 112762; (E) Kurtzipites andersonii Srivastava, GSC 112763; (F) Platanus-type pollen, GSC 112764; (G) Cranwellia rumseyensis Srivastava, GSC 112765; (H) ?Palcheripollenites sp. (although many specimens were observed, the form of the apertures is indeterminate; possibly an Anacolosidites sp.), GSC 112766; (I) Siberiapollis sp., GSC 112767; (J, Q) Tricolpites sp., (J) GSC 112768; (Q) GSC 112775; (K) Senipites drumhellerensis Srivastava, GSC 112769; (L) Cranwellia? sp., GSC 112770; (M, N) Azonia sufflata Wiggins; (M) GSC 112771; (N) GSC 112772; (O) Expressipollis sp., GSC 112773; (P) Pleuro sperma pollenites sp., GSC 112774; (R) Scabratiporites legibilis Samoilovich, GSC 112776; (S) Liliacidites sp., GSC 112777; (T–Z) Dinoflagellates; (T) ?Alterbidinium sp., GSC 112778; (U) Ovoidinium scabrum (Cookson and Hughes) Davey, GSC 112779; (V) ?Garddinium trabeulosum (Gocht) Alberti, GSC 112780; (W) cf. Horologinella sp., GSC 112781; (X) Kallosphaeridium minus (Cookson and Hughes) Helby, GSC 112782; (Y) Laciniadinium arcticum (Manum and Cookson) Lentin and Williams, GSC 112783; (Z) Spinidinium sp., GSC 112784.
maximum particle size is 6 cm (Fig. 7A). Facies association 2 in the Cantwell basin is located basinward of facies association 1 and contains south-to-southeast paleocurrent indicators (Fig. 7B).

**Facies Association 3.** The Cantwell Formation in the north-central part of the Cantwell basin is characterized by interbedded mudstone and sandstone. Individual mudstones and sandstones occur mainly in <2-m-thick beds that can be traced for hundreds of meters (Fig. 6C). The measured section at Double Mountain (DM1) (Fig. 8) is typical of facies association 3. The sandstones are massive to trough cross-stratified, and fine upward. Fluid escape structures are common in the sandstones. In the 353.5 m of lower Cantwell Formation exposed at DM1, only one conglomeratic unit was present. Average maximum particle size in this single unit is 3 cm. Facies association 3 in the Cantwell basin is located basinward of facies association 2 (Fig. 5). The thicker mudstone units at section DM1 are part of facies association 5 and will be discussed in that section.

**Interpretation of Facies Associations 1, 2, and 3.** Sedimentary structures in the conglomerates and sandstones of facies associations 1, 2, and 3 are characteristic of stream-flow deposits. Evidence for stream-flow processes in the conglomerates and sandstones includes the framework support, (o)(b)(i) imbrication, crude upward-finishing trends, lenticular geometries of individual units, trough cross-stratification, and unimodal paleocurrent indicators. The organized and imbricated conglomerates of facies associations 1 and 2 are typical of modern fluvial conglomerates that form when gravels are transported as bedload and deposited under waning flow by accretion of progressively smaller clasts in channels and on longitudinal bars of low-sinuosity stream systems (Collinson, 1986). Facies association 3 is interpreted as sheet flood deposits. Sheet flood deposits are formed by surges of sediment-laden water that spread out from the ends of stream channels on alluvial fans, resulting in laterally continuous deposits of sand (Bull, 1972). Evidence for sheet flood deposition includes the following: (1) the dominance of laterally continuous, normally graded sandstone, which suggests nonchannelized flows; and (2) individual bed thickness of less than 2 m, which implies that flows were rarely very deep.

Several basinward facies transitions can be inferred from the fluvial facies documented for facies associations 1, 2, and 3. Massive, boulder and cobble conglomerates (average maximum particle size = 11 cm) of facies association 1, located along the northern basin margin (i.e., Mount Sheldon (MS1) measured section adjacent to the Hines Creek fault) (Figs. 5 and 7), grade basinward into channelized cobble conglomerates (average maximum particle size = 6 cm) of facies association 2 (i.e., Polychrome Mountain, PC1, measured section). In turn, channelized cobble conglomerates grade basinward into massive and trough cross-stratified sheet sandstones of facies association 3 (i.e., Double Mountain, DM1, measured section). These basinward trends therefore include (1) a decrease in average maximum particle size (Fig. 7A), (2) a decrease in conglomerate (Fig. 5B), and (3) an increase in the organization of conglomerates. Paleocurrent and maximum particle size data also indicate southward sediment transport in all three facies associations (Fig. 7, A and B). Our interpretation of basinward facies transitions is supported by palynological age correlation which shows that all three facies associations (1–3) were deposited at roughly the same time, from late Campanian to early Maastrichtian (see Trop, 1996, Appendices 1 and 2, for details of age constraints).

We interpret the dominance of stream-flow facies, the abrupt south-to-southeastward change in grain size (Fig. 7A), and the basinward lithofacies trends as evidence for stream-dominated alluvial-fan deposition. Stream-dominated alluvial fans are fans whose surface processes are dominated by perennial stream flow (Collinson, 1986); they also have been referred to as wet fans (Schumm, 1977), and humid fans (Fraser and Suttner, 1986). Similar, ancient stream-dominated alluvial fan deposits have been documented in other northwestern Cordilleran sedimentary basins (Ridgway and DeCelles, 1993b). Coal distribution in the Cantwell basin, as well as in other studied coal-bearing basins, is related to depositional processes on stream-dominated alluvial fan deposits. The thickest coal seams in the Cantwell alluvial fan deposits occur in the proximal lithofacies. Coal development in the intervening middle and distal fan areas was probably suppressed by the high frequency of unconfined flow events and lateral channel mobility.

**Axial Sandy Braided Stream Systems**

**Facies Association 4.** The Cantwell Formation exposed along the east-west axis of the basin is characterized by a dominance of planar and trough cross-stratified sandstone and subordinate clast-supported, well-organized conglomerate (Fig. 9A). Sandstone and conglomerate units are laterally continuous. Internally, the sandstone sheets are marked by lateral discontinuity, with...
Numerous reactivation surfaces, and local scours (Fig. 9B). Individual foresets in the stratified sandstones have a maximum thickness of 75 cm. Facies association 4 is well exposed in the Dean Creek (DC1) measured section (Fig. 8). The 624-m-thick section of lower Cantwell Formation exposed at DC1 consists of amalgamated beds of massive and planar cross-stratified sandstone, and clast-supported conglomerate (Figs. 8 and 9B). Individual bed thicknesses range from 0.5 to 1.5 m. In the upper part of DC1, 40–60-m-thick, coarsening-upward packages have been documented (Fig. 9A). The base of the package is defined by a 2–8-m-thick laminated mudstone and coal unit, which grades upward into massive and planar cross-stratified sandstone, which is, in turn, overlain by a 10–20-m-thick unit of conglomerate marked by a channelized base (Fig. 9A).

Interpretation of Facies Association 4. Facies association 4 is interpreted as being formed by stream-flow deposits. Evidence for stream-flow processes includes the presence of planar- and trough cross-stratified sandstones; clast-supported, imbricated, well-organized conglomerates; and unidirectional paleocurrents recorded at each measured section. The abundance of planar and trough cross-stratified sandstones, with individual foresets less than 75 cm in thickness, indicates that deposition was primarily by subaqueous two-dimensional and three-dimensional ripples (Harms et al., 1982) in shallow channels. The lack of definable large channels in facies association 4 implies that deposition was laterally extensive and not restricted to a single main channel. We interpret facies association 4 as the product of deposition in a large axial, sandy braided stream system (Fig. 5). We further interpret that the axial braided stream system was partly fed by the stream-dominated alluvial fan systems to the north (facies associations 1, 2, and 3) (Fig. 5A). The axial stream system was the major trunk stream system that drained the entire Cantwell basin and, on the basis of paleocurrent analysis (Fig. 7B), exited the basin in the northeastern corner near the present Dean Creek area (DC1; Fig. 1B). The upward-coarsening packages documented at measured section DC1 may represent the progradation of coarser facies across the basin as a result of displacement on nearby basin-margin faults.

Lacustrine Systems

Facies Association 5. The Cantwell Formation within the south-central part of the basin is often characterized by 10–40-m-thick units of trough cross-stratified and massive sandstone in-
terbedded with 10–50-m-thick units of mudstone (Fig. 9, C and D). The trough cross-stratified and massive sandstones are lithologically similar to facies association 4 sandstones. The defining feature of facies association 5 is the thick mudstone deposits. Mudstone lithofacies in facies association 5 have varvelike laminations (Fig. 9E), and often contain ripple stratification with clay drapes, dewatering structures, flaser bedding, graded beds, convoluted bedding (Fig. 9F), and abundant large plant fragments. Facies association 5 is well exposed at the Panorama Mountain measured section (PA1) (Figs. 5 and 8). At this locality, mudstones with minor coals are interbedded with trough cross-stratified sandstones. Both the mudstones and sandstones are laterally continuous at the scale of the outcrops.

**Interpretation of Facies Association 5.** The abundance of fine-grained deposits in facies association 5 implies low-energy depositional processes with a large component of suspension fallout. The varvelike laminations in the mudstones indicate that sediment transport involved a component of gravitational settling of finer grain sizes. We interpret facies association 5 as suspension fallout (represented by the mudstones) and stream-flow (represented by the trough cross-stratified sandstones) deposits related to lacustrine and sandy braided stream environments, respectively. The presence of clay drapes on ripple laminations and flaser bedding indicates that flow velocity varied from a few tens of centimeters per second to stagnant. Convoluted bedding and dewatering structures in the mudstones are also indicators of episodic rapid deposition on top of existing water-saturated deposits. These types of processes are common in lacustrine depositional systems (Fouch and Dean, 1982). Periodically, axial sandy braided stream systems (part of facies association 4) migrated into lacustrine environments and deposited the trough cross-stratified sandstone.

The concentration of lacustrine mudstones in the southern part of the basin indicates that the deepest part of the Cantwell basin was often adjacent to the thrust-faulted southern margin of the basin (Fig. 5, A and B). This interpretation is consistent with data from our measured stratigraphic sections of the lower Cantwell Formation, which record a southward increase in thickness (Fig. 5B). The increase in stratigraphic thickness of the lower Cantwell Formation provides documentation of an asymmetric, southward-dipping basin profile.

**Marginal Marine Systems**

Previous studies have interpreted the depositional systems of the lower Cantwell Formation as entirely nonmarine. This study has recognized dinoflagellates and acritarch-bearing mudstones (Fig. 3, T–Z), interbedded with oncolitic (?) limestones (Fig. 10) in the upper part of the lower Cantwell Formation. If the dinoflagellates and acritarchs are indigenous to the sampled horizons, they would be indicative of a brackish water to marine depositional environment. In the Dean Creek section (DC1; Figs. 1B and 8), the samples from 234 and 331 m above the base of the section yielded an algal cyst assemblage dominated by cf. *Horologinella* (16 specimens seen) accompanied by rare occurrences of the dinoflagellates *Ovoidinium*, *Alterbidinium*, and *Laciniaadinium*, and other unidentified cysts. In the Polychrome Mountain section (PC1; Figs. 1B and 8), rare dinoflagellates occurred in samples from 48, 58.5, and 93 m that included one to three specimen...
records of Cliestospheridium, Hystrichoshaera, Ovoidalinium, Odontochitina, and Spiniferites (in order of decreasing number of records). The Double Mountain section (DM1; Figs. 1B and 8) yielded two different styles of algal cyst assemblages. The sample from 32 m yielded from one to three specimens of Scenedesmus, Pediastrum, Horologinella, Ovoidalinium, and Cliestosphe-ridium. Modern Scenedesmus lives in fresh water, Pediastrum in fresh to brackish, and the other taxa in brackish-to-marine waters. The six samples in DM1 section examined from between 241 and 353 m all contained dinoflagellates including from one to six specimens of Ovoidalinium, Laciniaomidium, Horologinella, Oligosphaeridium, Spiniferites, and Gardodinium.

The relative concentration of Horologinella and sometimes Ovoidalinium in a restricted number of samples appears to support a conclusion that these algal cysts were indigenous to the sampled horizons and indicative of a marine influence. Ovoidalinium and Gardodinium, however, are considered to have Early Cretaceous to Cenomanian and Early Cretaceous ranges, respectively (Lentin and Williams, 1985). These age ranges raise the question as to whether some or all the recovered dinoflagellates are indigenous to the sampled horizons or are reworked from Early Cretaceous marine rocks exposed on the margins of the Cantwell basin. Limestones, interbedded with dinoflagellate-bearing mudstones, having a maximum thickness of 50 cm, appear to contain oncolitic algal structures (Fig. 10). Recrystallization of the limestones often obliterated much of the original texture and made precise identification of any fossils difficult. Although oncolitic limestones have been documented from nonmarine deposits (Jerzykiewicz and Sweet, 1988), they are frequently associated with marine environments (Wilson, 1975; Scholle et al., 1983). On the basis of the close association between oncolitic limestones and mudstones containing marine dinoflagellates, we conclude that a marine influence in the upper part of the lower Cantwell Formation is a possibility. The possible marine deposits, based on the low diversity assemblage of dinoflagellates and the abundance of terrestrially derived, dispersed organic material, would have been the product of a restricted, marginal marine depositional environment.

STRUCTURAL CONTROLS ON BASIN DEVELOPMENT

Southern Basin Margin

Previous studies of the Cantwell basin have considered the McKinley segment of the Denali fault system as defining the southern basin margin (Fig. 1B) (Hickman et al., 1990). In past studies, the Cantwell basin has been interpreted as a strike-slip pull-apart basin that formed between the Hines Creek fault and the McKinley fault (Fig. 1B). Strike-slip displacement along the McKinley fault has been interpreted as the primary control on basin subsidence (Hickman et al., 1990).

Several new lines of evidence from this study indicate that a system of thrust faults (originally mapped by Hickman and Craddock, 1976; Sherwood and Craddock, 1979; Csejtey et al., 1986; Csejtey et al., 1992) defined the southern margin of the Cantwell basin (Fig. 1B). Our data (Fig. 11) indicate that these southward-dipping thrust faults, located north of the McKinley fault (Fig. 1B), were active during Cantwell Formation.
deposition. Intraformational angular unconformities and progressively tilted strata within the lower Cantwell Formation provide compelling evidence that the adjacent thrust faults were syn-depositional. The intraformational unconformities and tilted strata are well exposed in the area near measured section PA1 at Panorama Mountain (Figs. 1B and 12). Here the stratigraphically lowest Cantwell Formation beds are dipping 85°NW (Unit A in Fig. 12A). Unit A is separated from the overlying deposits of Cantwell Formation by an angular unconformity with 24° of discordance (Fig. 12A). This second package of rotated Cantwell Formation deposits has an average dip of 58°NW (Unit B in Fig. 12A). An angular unconformity with 19° of discordance separates Unit B from the highest stratigraphic package (Unit C in Fig. 12A). The uppermost package has an average dip of 36°NW. The contact with the upper Cantwell Formation volcanic rocks is located at the top of this package. The entire lower Cantwell Formation in this specific area has undergone 49° of northward (i.e., basinward) rotation and contains at least two major intraformational unconformities.

The amount of rotation within the lower Cantwell Formation, proximal to the southern basin margin, varies along strike. For example, directly east of Revine Creek, our mapping indicates 35° of progressive northward rotation (Fig. 11). In contrast, west of Revine Creek, mapping indicates 50° of progressive northward rotation within the lower Cantwell Formation (Fig. 11). Figure 12B shows a typical example of an angular unconformity and Figure 12C shows the progressive tilting of strata documented along the southern margin of the Cantwell basin. The presence of angular unconformities along the southern basin margin has been recognized in previous studies (Newell, 1975, Moose Creek area; Sherwood, 1979, Wood River area). On the basis of our mapping and structural data from previous studies, the package of progressively tilted strata and unconformities can be traced for most of the 135 km length of the southern margin of the Cantwell basin.

We interpret the progressive tilting within the lower Cantwell Formation strata and the associated intraformational angular unconformities as forming when Cantwell deposits, located in the footwall of bordering thrust faults, were progressively tilted basinward during fault displacement and incorporated into a growth footwall syncline. Footwall growth synclines, as defined

Figure 8. Measured stratigraphic sections of the Cantwell basin showing changes in lithofacies from the northern basin margin (MS1) to the southern basin margin (PA1). See Figures 1B and 5 for section locations. Open circles represent clast-supported conglomerate. Stippled pattern represents massive and trough cross-stratified sandstone. Horizontal dashed lines represent mudstone. Double hashed symbols represent igneous intrusion. S, silt; M, sand (medium grain size); P, pebble; B, boulder. Due to space limitations, only a 300 m representative part of each measured section is shown. MS1—Mount Sheldon; PC1—Polychrome Mountain; DM1—Double Mountain; DC1—Dean Creek; PA1—Panorama Mountain.
Figure 9. (A) Facies association 4 of the Cantwell basin. Fsm—mudstone; St—trough cross-stratified sandstone; Gct—trough cross-stratified conglomerate. Arrows outline erosional surface between sandstone and conglomerate. Person (lower right) for scale. (B) Amalgamated channels of cross-stratified sandstone typical of facies association 4. Arrows outline one channelized surface. Bedding dips to right. Person (lower right center) for scale. (C) Steeply dipping, interbedded mudstone (F) and trough cross-stratified sandstone (St) of facies association 5 common in the southern part of the Cantwell basin. Dark recessive units are mudstone (F) and prominent lighter units are sandstone (St). Bedding dips 85° to left. (D) Close-up photograph of thinly bedded mudstone (Fsm) and trough cross-stratified sandstone (St) typical of facies association 5. Bedding dips steeply to left. Person (arrow) for scale. (E) Laminated mudstone lithofacies of facies association 5 common along the southern margin of the Cantwell basin. Scale is 10 cm long. (F) Convoluted bedding (arrows) associated with soft sediment deformation that often characterizes mudstones of facies association 5. Scale is 10 cm long.
Figure 10. Oncolitic (?) limestone (L) interbedded with marine dinoflagellate-bearing mudstone (M) in the lower Cantwell Formation. Arrow points to a recrystallized oncolite. Stratigraphically, this bed is 210 m below the contact with the upper Cantwell Formation volcanic rocks in measured stratigraphic section DM1 (Fig. 1B) (Trop, 1996). Location of measured section DM1 is Healy (C5) quadrangle, Alaska, SW 1/4 sec. 15, T. 15 S., R. 10 W.

Figure 11. Sketch map of part of the south-central margin of the Cantwell basin showing bedding orientation and location of intraformational unconformities in the lower Cantwell Formation (Kcs). Note the northward decrease in dip away from the thrust faults that formed the southern boundary of the Cantwell basin. Area shown on map is located east of the Nenana River near measured section PA1 on Figure 1B. Note the change in strike and dip across the intraformational unconformities. See text for additional discussion.

Here, are footwall folds in which sedimentation took place during structural growth of the syncline. During each major episode of thrust fault deformation, Cantwell Formation sediments in the proximal footwall area of the fault were tilted and eroded, and subsequent lithofacies were deposited on an angular unconformity (Fig. 13). Packages of progressively tilted strata, each bounded by angular unconformities, are common elements of thrust-derived deposits within growth footwall synclines (Riba, 1976; Anadon et al., 1986; DeCelles et al., 1991, 1993; Burbank and Vergés, 1994; Vergés et al., 1996; Hoy and Ridgway, 1997). The progressively tilted strata associated with growth folds have been referred to as growth strata (see Suppe et al., 1992; Schneider et al., 1996).

Compositional data from the lower Cantwell Formation along the southern basin margin also provides evidence for syndepositional thrusting (Ridgway et al., 1994; Trop and Ridgway, 1995). Limestone conglomerate clasts, for example, common in measured section RV1 (Fig. 14), lo-
cated adjacent to the southern basin margin thrust fault system, are similar to nearby limestones located in the hanging walls of adjacent thrust faults. Conodonts extracted from these limestone conglomerate clasts in the Cantwell Formation yield an Ordovician to Early Devonian age (Csejtey et al., 1986), indicating that they were likely derived from the Ordovician–Devonian limestones found in the hanging wall of a nearby thrust fault (Fig. 14). A detailed petrographic study of the sandstones of the lower Cantwell Formation along the southern basin margin, coupled with paleocurrent data, indicates that rocks exposed by the thrust faults contributed detritus to the Cantwell basin (Trop et al., 1995; Trop and Ridgway, 1997). We interpret the provenance documented for the Cantwell Formation along the southern basin margin, the angular unconformities, the growth strata, and the northward-directed paleocurrent indicators (Fig. 7B) as direct evidence that thrust fault deformation and Cantwell Formation sedimentation were synchronous.

**Northern Basin Margin**

The Hines Creek fault forms the northern structural boundary of the Cantwell basin (Fig. 1B). The type of structural feature represented by the Hines Creek fault in the study area has been controversial, partly due to a lack of unequivocal surface exposure data (Brease, 1993). The 275-km-long Hines Creek fault was originally interpreted as an older (post–95 Ma) segment of the strike-slip Denali fault system that represented a major terrane boundary (Grantz, 1966; Wahrhaftig et al., 1975). On the basis of additional geologic mapping and geophysical data, Csejtey et al. (1982) interpreted the Hines Creek fault as a mid-Cretaceous fault that was not a major terrane boundary fault. More recent studies (Nokleberg et al., 1989, 1992; Nokleberg et al., 1994), east of the Cantwell basin in the Mount Hayes quadrangle, interpret the Hines Creek fault as part of a series of Cenozoic thrust faults that are contained within the Yukon-Tanana terrane.

Several important findings from our study suggest that the Hines Creek fault was active during the Late Cretaceous from the Campanian to Maastrichtian, and that it played an important role in the formation of the Cantwell basin. First, the proximal alluvial fan deposits concentrated along the Hines Creek fault in the lower Cantwell Formation are consistent with deformation and uplift during Cantwell Formation deposition (Figs. 5 and 6A). Second, the Cantwell Formation conglomerates along the Hines Creek fault contain as much as 40% reworked Cantwell Formation clasts. An abundance of reworked Cantwell Formation conglomerate clasts is well documented at the Polychrome Mountain measured section (Fig. 14). We interpret the clast composition data, coupled with paleocurrent data (Fig. 7B), as evidence that periodically during lower Cantwell Formation deposition, the Cantwell Formation proximal to the Hines Creek fault was uplifted, eroded, and incorporated into younger Cantwell Formation deposits along the northwestern basin margin. In the central

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**Figure 12. Photographs of intraformational unconformities and rotated beds in the lower Cantwell Formation along the southern basin margin.** Wavy black lines indicate intraformational unconformities and tadpole symbols represent dip of bedding. (A) View to the east from Nenana River on Figure 11. Stratigraphic up and north are to the left. The stratigraphically lowest beds (Unit A) are dipping 85°. Unit A is separated from the overlying deposits by an angular unconformity. The second package of rotated beds (Unit B) has an average dip of 58°. An angular unconformity separates Unit B from the highest stratigraphic package (Unit C), which has an average dip of 36°. The entire lower Cantwell Formation in this area has undergone 49° of northward (i.e., basinward) rotation and contains at least two major intraformational unconformities. (B) Intraformational unconformity in the Cantwell Formation. View is of outcrops located east of Revine Creek on Figure 11. Stratigraphic up and north are to the right. Beds south (left) of the unconformity are dipping 59°, whereas beds north of the unconformity are dipping 46°. (C) Progressive rotation of strata in the lower Cantwell Formation. Stratigraphic up and north are to the right. Bedding systematically decreases from 75° on the left (south) to 65° on the right (north). View is of outcrops located west of Revine Creek on Figure 11. Person (arrow) for scale.
and eastern parts of the Cantwell basin, the Hines Creek fault is covered by the Cantwell Formation (Wahrhaftig et al., 1975; Csejty et al., 1992) and is interpreted as a blind fault during Cantwell Formation deposition. Despite being covered by the Cantwell Formation in the central and eastern parts of the Cantwell basin, stratigraphic evidence suggests that the Hines Creek fault actively influenced Cantwell Formation sedimentation along this part of the northern basin margin. For example, Sherwood (1979) has interpreted the Cantwell Formation, north of the Hines Creek fault in the eastern part of the basin, as a condensed section based on minor angular unconformities and abrupt northward thinning of the lower Cantwell Formation. In summary, we interpret the Hines Creek fault as a reverse or thrust fault (in agreement with geologic mapping of Csejty et al., 1992, and Nokleberg et al., 1992) that was active during lower Cantwell Formation deposition. Periodic Late Cretaceous displacement on the Hines Creek fault resulted in southward transport of sediments into the Cantwell basin (Fig. 7B). Our interpretation of Late Cretaceous thrust displacement on the Hines Creek fault does not preclude the possibility of an earlier history of strike-slip displacement as suggested by previous studies (Grantz, 1966; Wahrhaftig et al., 1975; Gilbert and Bundtzen, 1983).

**IMPLICATIONS OF THE STUDY**

Regional Tectonic Setting

We interpret the thrusting associated with the formation and development of the Cantwell basin to be a result of regional shortening related to the Mesozoic accretionary development of southern Alaska. In south-central Alaska, mid-Cretaceous to Late Cretaceous shortening was in response to accretion of the Wrangellia composite terrane (terminology of Plafker et al., 1989) to the continental margin of North America (i.e., the Yukon-Tanana terrane) (Fig. 15) (Csejty et al., 1982; Gilbert and Bundtzen, 1983). The Wrangellia composite terrane consists of the Alexander, Peninsular, and Wrangellia terranes and represents the largest allochthonous crustal fragment of southern Alaska. The precise time of final Cretaceous accretion of the Wrangellia composite terrane is not perfectly constrained. Geologic data point to a late Early to early Late Cretaceous (Albian–Cenomanian) docking of the Wrangellia composite terrane in its present position (Nokleberg et al., 1994), whereas plate reconstructions indicate that northward displacement and docking of the Wrangellia composite terrane could not have occurred prior to the Campanian (Engbretson et al., 1985). Mid-Cretaceous to Late Cretaceous docking of the Wrangellia composite terrane resulted in underthrusting, folding, and metamorphism of an extensive Mesozoic flysch basin (Kahiltna assemblage in Fig. 15) located between the impinging Wrangellia composite terrane and the North American continental margin (Yukon-Tanana terrane on Figure 15) (Csejty et al., 1982; Nokleberg et al., 1994). Continued mid-Cretaceous to Late Cretaceous convergence resulted in the obduction of the Wrangellia composite terrane onto the continental margin of North America (Csejty et al., 1982) and the development of an extensive suture zone. The present surface expressions of this Late Cretaceous suture zone are the tectonic melange deposits located along the southern Alaska Range (Csejty et al., 1992), ~5–10 km south of the Cantwell basin. The tectonic melange deposits consist of intensely deformed and sheared blocks of Paleozoic limestone, ophiolitic rocks, and Mesozoic flysch-related argillite and chert (units Kms and Kmn of Csejty et al., 1992). Development of the suture zone associated with obduction was characterized by extensive thrusting and folding of the Wrangellia composite terrane, the intervening Mesozoic flysch basin, and the ancient North American
The importance of this mid-Cretaceous to Late Cretaceous orogenic event in the tectonic development of south-central Alaska and the formation of the Cantwell basin is documented by magnetotelluric surveys across the central and eastern Alaska Range (Stanley et al., 1990). Magnetotelluric data suggest that Mesozoic flysch deposits have been tectonically emplaced northward beneath the southern Yukon-Tanana terrane for more than 50 km (Fig. 15). One of the north-south magnetotelluric lines transects the central Cantwell basin (Fig. 5 of Stanley et al., 1990), and indicates that at deeper structural levels (below 5 km) the Cantwell basin is underlain by underthrust Mesozoic flysch deposits (Fig. 15).

Seismic refraction data from the trans-Alaska crustal transect, located 100 km to the east of the Cantwell basin, also indicate that the southern Yukon-Tanana terrane is underlain by underthrust flysch deposits (Beaudoin et al., 1992). We interpret the Late Cretaceous Cantwell basin as having formed in the upper structural levels, above the deeper zone of underthrusting, along the suture zone between the Wrangellia composite terrane and the North American continental margin (Fig. 15). The presence of Cenomanian fossils in strongly deformed and regionally metamorphosed Mesozoic flysch deposits (Csejtey et al., 1992) suggests that the unmetamorphosed Campanian and Maastrichtian Cantwell Formation deposits record later stages of the major Late Cretaceous orogenic event.

**Basin Formation**

New data from this study, coupled with regional tectonic models (Csejtey et al., 1982; Pfafker et al., 1989; Nokleberg et al., 1994), indicate that the Cantwell basin formed on a series of active thrust faults that were associated with a Late Cretaceous suture zone (Fig. 15). This new thrust-top basin interpretation is based on (1) the regional intraformational unconformities and growth strata documented in the Cantwell Formation associated with thrust faults along the southern basin margin; (2) the coarse, alluvial fan deposits concentrated along the northwestern basin margin adjacent to the Hines Creek fault; (3) provenance and paleocurrent data that indicate both the southern basin margin thrust faults
Figure 15. Schematic paleotectonic block diagram of south-central Alaska during the Late Cretaceous based on the regional tectonic models of Csejty et al. (1982), Plafker et al. (1989), and Nokleberg et al. (1994), and this study. The surface data used to construct this diagram is taken from the geologic map of the Healy quadrangle by Csejty et al. (1992). The length of the block diagram is -180 km. During the Late Cretaceous, accretion of the Wrangellia composite terrane (WCT) resulted in regional shortening throughout south-central Alaska. The southeast-dipping Talkeetna thrust fault marks the northern extent of the WCT (Csejty et al., 1982). Docking of the WCT resulted in underthersting and folding of the Mesozoic flysch basin (Kahiltna assemblage) located between the impinging WCT and the North American continental margin. The Yukon-Tanana terrane represents the Late Cretaceous North American continental margin, Magnetotelluric and seismic data indicate that Mesozoic flysch deposits of the Kahiltna assemblage have been tectonically emplaced northward beneath the southern Yukon-Tanana terrane for more than 50 km (Stanley et al., 1990; Beaudoin et al., 1992). The Late Cretaceous Cantwell basin formed in the upper structural levels, above the deeper zone of underthrusting, along the suture zone between the WCT and the North American continental margin. See text for additional discussion.

Our analysis suggests that there were two major controls on the formation and stratigraphic evolution of the Cantwell basin. First, episodic uplift and translation of the Cantwell basin along the Hines Creek fault resulted in cannibalization of existing Cantwell deposits and produced a condensed section (~700 m) of Cantwell Formation along the eastern basin margin. The other major control on basin development was subsidence along the southern basin margin induced by hinterland thrust loading proximal to the suture zone. The accumulation of over 4000 m of Cantwell deposits adjacent to the thrust-bounded southern basin margin and the asymmetric basin geometry (Fig. 5B) are interpreted to be the result of subsidence due to thrust loading. The presence of (1) intrabasinal unconformities and sequentially tilted strata and (2) diagnostic Cantwell Formation conglomerate clasts derived from the uplifted hanging walls of nearby thrust sheets provides strong evidence for syndepositional thrusting during the development of the southern basin margin.

**Strike-Slip Displacement Along the Denali Fault**

The Denali fault system is considered one of the most important tectonic features in the northwestern Cordillera (LaVernia, 1978; Twitchell et al., 1978; Eibach, 1985; Plafker and Berg, 1994). On the basis of previous studies that have interpreted the Cantwell basin as a Paleogene strike-slip basin, the lower Cantwell Formation was interpreted as representing the oldest synorogenic deposit directly associated with strike-slip displacement along the entire Denali fault system (Ridgway et al., 1992b). The age of the Cantwell Formation, therefore, was thought to provide one of the few geochronologic constraints on the timing of the early development of the Denali fault system, especially along the
McKinley segment. Results of this study indicate that the Denali fault system is younger than the tectonics involved in the formation of the Cantwell basin. This interpretation of the Late Cretaceous Cantwell basin is in agreement with the geologic mapping of Csejtey et al. (1992) which documents offset of Late Cretaceous thrust faults by the Cenozoic Denali fault system. Within the general framework of previous regional tectonic models (Csejtey et al., 1982; Nokleberg et al., 1994), we interpret the Cantwell basin as part of the Cretaceous accretionary orogenic event, whereas the Cenozoic, post-creational strike-slip Denali fault system developed within the older Cretaceous suture zone.

In light of this reinterpretation of the lower Cantwell Formation, the oldest documented synorogenic strike-slip deposits along the eastern Denali fault system are the late Eocene–Oligocene Amphitheatre Formation located in the Saint Elias Mountains, Yukon Territory (Ridgway and DeCellis, 1993a; Ridgway et al., 1995a). Along the western part of the Denali fault system, several strike-slip basins have been described that contain mostly Oligocene and Miocene deposits, and smaller amounts of possibly Paleocene deposits (Gilbert, 1981; Dickey, 1984). Additional detailed geochronologic studies are needed on all the strike-slip basins along the Denali fault system, but much of the available data from studied synorogenic sedimentary deposits suggest that the earliest major displacement on the Denali fault system occurred during the late Eocene and Oligocene (Ridgway et al., 1992b).

Regional Stratigraphic Correlations

The marine influence recognized in the upper lower Cantwell Formation may represent the same major Campanian transgressive event (i.e., the Bearpaw transgression) found in several sedimentary basins in western Canada. From a regional stratigraphic perspective, the lower Cantwell Formation is correlative to the upper Tango Creek and Brothers Peak Formations of the Sustut Group, Bowser basin, British Columbia (A. R. Sweet, 1995, unpub. data) (Fig. 16; the Belly River/Brazeau, Bearpaw, and St. Mary River/Horseshoe Canyon Formations, Alberta foreland basin (Jerzykiewicz and Sweet, 1988) (Fig. 16; the middle part of the Bonnet Plume Formation of the Yukon Territory; and the Little Bear and East Fork Formations of the Brackett basin, Northwest Territories (Nichols and Sweet, 1993) (Fig. 16). These stratigraphies contain marine or marginal marine strata of late Campanian–early Maastrichtian age.

Documentation of marine influence during the late Campanian in the Cantwell basin permits the first regional correlation of the eustatic Bearpaw transgressive event (Bearpaw cyclothem; Table 3 in Hancock and Kauffman, 1979) into south-central Alaska. On the basis of previous studies of the extent of the Bearpaw transgression (Hancock and Kauffman, 1979; Nichols and Sweet, 1993), the main body of the Bearpaw sea was located to the north of the Cantwell basin (Fig. 16). The sea probably entered the Cantwell basin from the fluvial drainage outlet in the northeast corner of the basin (Fig. 7B). Recognition of the Bearpaw transgression event in south-central Alaska should allow for more accurate paleogeographic reconstructions of North America during the Late Cretaceous.

CONCLUSIONS

(1) Previous geochronologic studies have placed the Cantwell Formation in the Paleocene. New data based on palynologic analyses indicate that the lower Cantwell Formation was deposited during the late Campanian to early Maastrichtian. On the basis of published regional tectonic studies and this new age constraint, the formation of the Cantwell basin was coeval with Late Creta-
ceous thrusting associated with accretionary tectonics in southern Alaska.

(2) Reconstruction of lower Cantwell Formation depositional systems demonstrates that sedimentation was strongly influenced by an asymmetric basin floor. The basin asymmetry resulted in a concentration of fine-grained lacustrine environments adjacent to the deeper southern basin margin. In the central part of the basin, axial braided stream systems and lacustrine environments interfingered with stream-dominated alluvial fan systems that flowed south to southeast away from the northern basin margin.

(3) Previous studies have interpreted the lower Cantwell Formation as an entirely nonmarine unit. The presence of abundant terrestrially derived organic material, marine dinoflagellates and oncolitic(? limestones is indicative of a marginal marine depositional environment in the upper part of the lower Cantwell Formation. The marine influence recognized in the Cantwell Formation may represent the same major Campanian transgressive event as the Bearpaw of the Cordilleran foreland basin.

(4) New data indicate that the Cantwell basin formed as a thrust-top basin along a Late Cretaceous suture zone between the Wrangellia composite terrane and the Northern American continental margin in south-central Alaska. This interpretation is based on (1) the Late Cretaceous age documented for the lower Cantwell Formation; (2) the regional intraformational unconformities and growth strata recognized in the Cantwell Formation associated with thrust faults along the southern basin margin; (3) the proximal alluvial fan deposits concentrated along the northwestern basin margin adjacent to the Hines Creek fault; and (4) compositional and paleocurrent data indicating that the southern basin margin thrust faults and the Hines Creek fault (i.e., the northern basin margin) were both active during Cantwell Formation deposition. The Hines Creek fault defined the northern leading edge of the thrust-top basin, whereas the syndepositional thrust faults, located along the southern margin of the basin, formed the trailing edge of the basin.

(5) The Denali fault system is considered to be one of the key tectonic features in the development of the northwestern Cordillera. On the basis of previous studies that have interpreted the Cantwell basin as a Paleogene strike-slip basin, the Cantwell Formation was interpreted as representing the oldest synorogenic deposit directly associated with strike-slip displacement along the Denali fault system. The age of the Cantwell Formation, therefore, was thought to provide one of the few geochronologic constraints on the timing of the early development of the Denali fault system. Results of this study document that the Cantwell basin formed as a part of the Cretaceous accretionary-collisional orogenic event, prior to the development of the postaccretionary Cenozoic Denali fault system.

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