

## Late Ordovician environmental changes in Carnic Alps and central Nevada : a comparative study

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*Key words.* – Ordovician, Carnic Alps, Central Nevada, Stratigraphic succession, Glacial interval,

*Abstract.* – Correlation of the late Ordovician stratigraphic and faunal successions in the Carnic Alps, which lay in a mid-latitude site at the time, with those in Nevada, which was in the tropics at the time, reveal certain similarities. During much of the late Ordovician glacial interval, deep shelves in both areas were sites of carbonate debris flow accumulations. The debris was derived from inner or shallow shelf environments. Karst topographies developed in inner or shallow shelves in both areas during the later phase of glaciation and sea level drawdown. A quartz sand spread widely at the end of the glacial interval on deep shelf-slope environments in both areas. Perhaps coincidentally, shelves in both areas were uplifted and exposed by tectonism after the late Ordovician glacial episode.

### Changements environnementaux dans les Alpes carniques et le Nevada central au cours de l'Ordovicien terminal : une étude comparative

*Mots clés.* – Ordovicien, Alpes Carniques, Nevada central, Succession stratigraphique, Intervalle glaciaire.

*Résumé.* – La comparaison entre les successions stratigraphiques et les enregistrements fauniques de l'Ordovicien terminal des Alpes carniques (situés en paléolatitudes moyennes) et ceux du Nevada (en paléolatitudes tropicales) présente certaines similitudes. Durant la majorité de l'intervalle glaciaire fini-ordovicien, les deux secteurs géographiques sont représentés par des plates-formes profondes dont la sédimentation dominante était composée de « debris flow », transportés depuis des environnements de plate-forme interne ou peu profonde. La dernière phase glaciaire et la chute finale du niveau de la mer ont favorisé une intense karstification dans les domaines de plates-formes, internes ou peu profondes. Dans les environnements profonds des plates-formes, cet intervalle est caractérisé par la mise en place d'un dépôt sableux largement répandu à la faveur de ruptures de pente et de talus. Les plates-formes des deux secteurs ont peut-être subi une remontée isostatique et ont ensuite été exondés par des processus tectoniques après l'épisode glaciaire fini-ordovicien.

## INTRODUCTION


Late Ordovician climate and related environmental and faunal changes comprise one of the clearest examples of linkages between climate changes and faunal and environmental changes within the Phanerozoic [Brenchley, 1989; Brenchley *et al.*, 1995; Finney *et al.*, 1997; 1999; Rong and Harper, 1999; Kump and others, 1999; Sutcliffe *et al.*, 2000]. Because of the significance of that episode for documenting the impacts of climate and environmental changes on organisms, the Ordovician Subcommittee of the International Stratigraphic Commission designated study of late Ordovician climate change as one of its projects under their GOES (Global Ordovician Earth Systems) program. A symposium based on late Ordovician studies within the program was held at the 1999 meetings on the Ordovician System in Prague [Kraft and Fatka, 1999]. This comparative study of the late Ordovician faunal and environmental changes in mid-latitude (Carnic Alps) and low latitude sites (Nevada)

is part of an on-going analysis of the impacts of late Ordovician climate and related environmental changes on organisms conducted as part of the Ordovician GOES project.

Sutcliffe *et al.* [2000] and Ruddiman [2001, p. 126] discussed the development, size, extent and duration of the late Ordovician ice sheet that formed over western Gondwana. Sutcliffe *et al.* [2000] described two cycles in the ice sheet development based on their studies of Upper Ordovician glacial rocks in northern and southern Africa. Glacial conditions were established initially "in the early *extraordinarius* Zone" [Sutcliffe *et al.*, 2000, p. 968] (Late Ordovician Series, Stage and graptolite Zone correlations are indicated in table I). Impacts of glaciation and related sea-level fall on organismal extinctions have been described in a number of studies, among them are those of Brenchley [1989], Brenchley *et al.* [1995], Chen Xu *et al.* [2000], Finney *et al.* [1997, 1999], Sutcliffe *et al.* [2000] as well as those in Kraft and Fatka [1999]. Glaciation and related en-

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TABLE I. – Ashgill Series, Stages and graptolite zones with approximate time of sea level changes indicated [modified from Sutcliffe *et al.*, 2000].  
 TABL. I. – Série ashgillienne, étages et zones à graptolites avec indication approximative des variations du niveau de la mer [modifié d'après Sutcliffe *et al.*, 2000].

SERIES	STAGE	BIOZONE	S.L.
Llandoveryan	Rhuddanian	<i>açuminatus</i>	→ Rise 
Ashgillian	Hirnantian	<i>persculptus</i>	
		<i>extraordinarius</i>	
	Rawtheyan	<i>pacificus</i>	

environmental changes continued throughout the *extraordinarius* zone into the *persculptus* zone, ending during the *persculptus* zone [Finney *et al.*, 1999; Sutcliffe *et al.*, 2000].

Sutcliffe *et al.* [2000] summarized late Ordovician environmental and related faunal changes in southern Hemisphere high latitudes. Brenchley *et al.* [1995] Finney *et al.* [1997; 1999], Rong and Harper [1999] and Chen Xu *et al.* [2000] drew attention to primarily low latitude environmental and faunal changes. Among the several northern Gondwanan, mid-latitude late Ordovician faunal successions, the classical late Ordovician sequence in the Carnic Alps is of special interest because it bears conodonts, rare graptolites, certain chitinozoans, trilobites, brachiopods and certain other faunal elements that enable correlations with both low and mid-latitude late Ordovician successions. Schonlaub [1992], Schonlaub and Histon [2000], and Ferretti and Schonlaub [2001] indicated that the Carnic Alps lay between 40 and 50 degrees south latitude in the late Ordovician based upon both faunal and remnant magnetism analyses. Schonlaub [1992, fig. 6] indicated that during the

latest Ordovician (Ashgill), the Carnic Alps area was separate from certain other areas in which relatively similar late Ordovician stratigraphic successions are known, such as those in Spain, France and Bohemia. Because Schonlaub [1992] suggested that the Carnic Alps was separated from other areas during the late Ordovician, this study has at its focus comparison of the Carnic Alps late Ordovician sequences with coeval well-studied sequences in Nevada.

THE CARNIC ALPS

As Ferretti and Schonlaub [2001] pointed out, late Ordovician faunas have been known from the Carnic Alps for almost 130 years. Schonlaub and Histon [2000] summarized stratigraphic and faunal data for occurrences of trilobites, brachiopods, conodonts, bryozoans, and cystoids in the Carnic Alps late Ordovician sequence. Ferretti and Schonlaub [2001] described late Ordovician conodonts from a number of sites. Faunal collecting in field seasons of 2000 and 2001 added graptolites (*Persculptograptus persculptus* and normalograptids) at new localities (noted in fig. 1 and fig. 2) as well as new trilobite and brachiopod material to faunal data cited in Schonlaub and Histon [2000]. The occurrences of *P. persculptus* and the new analysis of late Ordovician conodonts [Ferretti and Schonlaub, 2001] enable relatively more precise correlation of late Ordovician environmental and faunal changes in the Carnic Alps with those in Nevada than had been possible previously. The presence of *Mucronaspis*, and certain brachiopods indicative of *Hirnantia* faunas enable correlation with high latitude successions described in Sutcliffe *et al.* [2000, fig. 2].

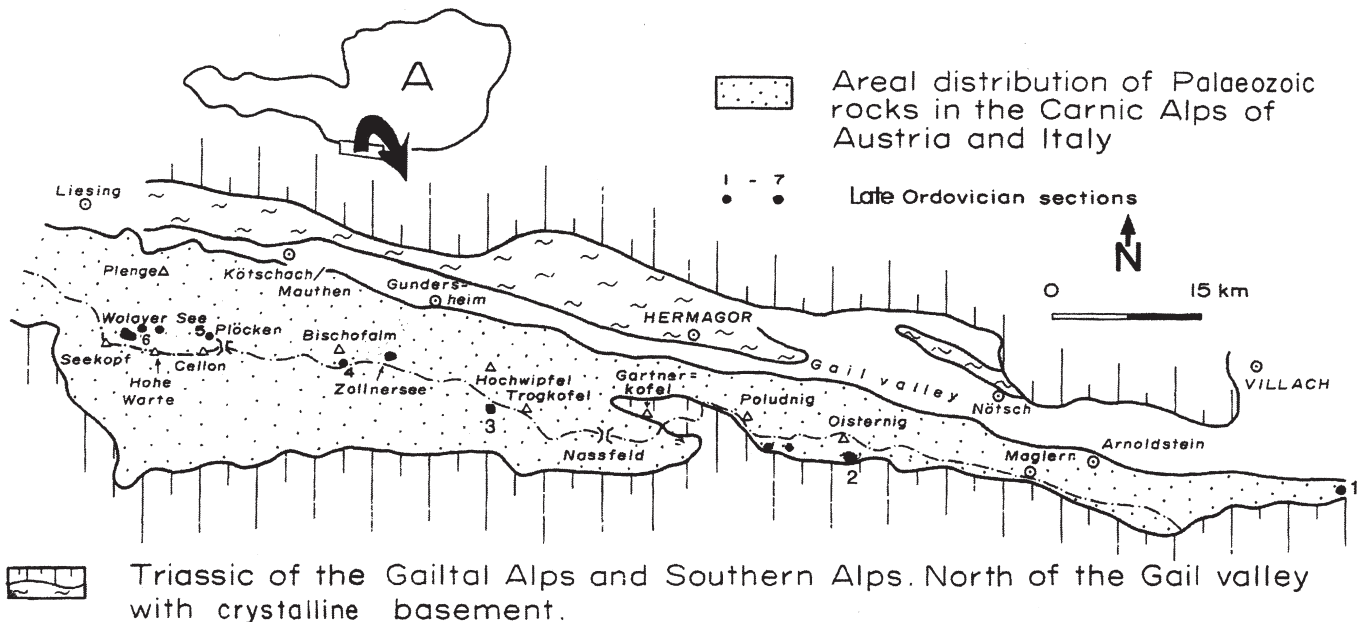


FIG. 1. – Map of Carnic Alps region (Austria and Italy) showing locations of late Ordovician stratigraphic sections mentioned in text. (1) Feistritz Graben in the Karawanken; (2) Uggwa stream section at Rifugio Nordio; (3) Valbertad; (4) Hoher Trieb; (5) Cellon; (6) Rauchkofel Boden. (Plocken facies is seen at sites 1-5 and Wolayer facies is at site 6) [after Schonlaub, 1988, Fig. 1].

FIG. 1. – Carte de la région des Alpes carniques (Autriche et Italie) avec localisation des coupes stratigraphiques de l'Ordovicien terminal citées dans le texte. 1) graben de Feistritz en Karawanken ; 2) coupe de la rivière d'Uggwa à Rifugio Nordio ; 3) Valbertad ; 4) Hoher ; 5) Cellon ; 6) Rauchkofel Boden (le faciès Plocken apparaît dans les points 1 à 5 et le faciès Wolayer dans le point 6) [d'après Schonlaub, 1988, Fig. 1].

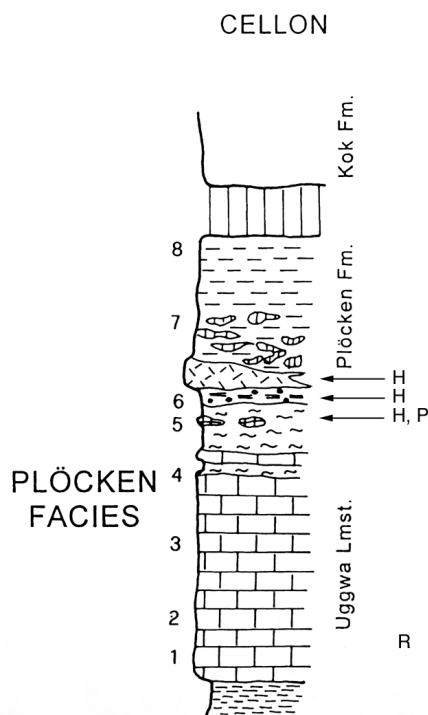


FIG. 2. – Late Ordovician stratigraphic section at Cellon indicating stratigraphic positions of *Hirnantia* fauna (H), *Perculptograptus persculptus* (P), and Rawtheyian fauna (R). Ferretti and Schonlaub [2001, p. 9-10] state that “shaley mud intercalations of the uppermost Uggwa Limestone grade, in the Cellon section, to the arenaceous and bioclastic limestones of the Plocken Formation.” They [Ferretti and Schonlaub, 2001, p. 10] said that *Hirnantia* faunas have been obtained in the Cellon section from the strata near the top of the Uggwa and from layers in the lower part of the Plocken. The indicated occurrence of *P. persculptus* is in silty shales which Schonlaub (oral commun., 2001) includes within the uppermost part of the Uggwa. Ferretti and Schonlaub [2001, p. 8-10] listed *A. ordovicicus* conodont faunas from bed number 4, which is in the upper part of the Uggwa, and from beds 6 and 7, which are in the Plocken. Bed numbers are those of Walliser [1964]. The Uggwa – Plocken formation boundary has not been indicated because of the essentially transitional lithologic aspects of the boundary interval [Figure is adapted from Ferretti and Schonlaub, 2001, Text-fig. 2].

FIG. 2. – Coupe stratigraphique de l’Ordovicien terminal à Cellon avec indication des positions de la faune à *Hirnantia* (H), à *Perculptograptus persculptus* (P) et faune rawtheyienne (R). Ferretti et Schonlaub [2001, p. 9-10] affirment que des intercalations d’argilites schisteuses du Calcaire supérieur d’Uggwa passent graduellement (dans la coupe de Cellon) aux calcaires bioclastiques et sableux de la formation de Plocken. Selon Ferretti et Schonlaub [2001, p. 1] les faunes à *Hirnantia* obtenues dans la coupe de Cellon proviennent des couches près du sommet d’Uggwa et des niveaux de la partie inférieure de Plocken. Ils ont indiqué la présence de *P. persculptus* dans des schistes sableux, lesquels sont considérés comme la partie supérieure d’Uggwa par Schonlaub (commun. oral, 2001). Ferretti et Schonlaub [2001, p. 8-10] ont présenté une liste de conodontes associés à *A. ordovicicus* depuis la couche numéro 4 (partie supérieure d’Uggwa) et depuis les couches 6 et 7 (Plocken). La numérotation des couches est celle de Walliser [1964]. La limite entre les formations d’Uggwa et de Plocken n’a pas été indiquée étant donné le caractère essentiellement progressif de leur transition (la figure est modifiée d’après celle de Ferretti et Schonlaub [2001] Text-fig. 2).

### Wolayer Facies

Two distinct lithologic facies characterize the Carnic Alps late Ordovician succession [Schonlaub and Histon, 2000; Ferretti and Schonlaub, 2001, text-fig. 2]. The Wolayer facies is a thick to massively-bedded crystalline limestone. Thin section study of these carbonates revealed that much of the rock is composed of crinozoan and bryozoan fragments [Dullo, 1992; Kreutzer, 1992]. Dullo [1992] sug-

gested that these limestones are composed primarily of clasts derived from mounds in which cystoids and bryozoans formed a community of baffling organisms. He suggested that these communities lived in a shallow marine shelf setting. Dullo [1992] used cathode luminescence to study cements within the upper part of the Wolayer facies limestones. He concluded from that analysis that the Wolayer facies environments had been exposed during glacio-eustatic sea level fall in the late Ordovician. Field study of these carbonates indicates that a karst formed on Wolayer facies rocks and that the superjacent mid to upper Silurian strata lie on them disconformably. Wolayer facies faunas include *Amorphognathoides ordovicicus* zone conodonts [Ferretti and Schonlaub, 2001] as well as brachiopods and trilobites indicative of late Ordovician age [Schonlaub and Histon, 2000].

### Plocken Facies

Limestones in the upper part of the Uggwa Formation are part of a coeval facies. The Uggwa limestones are composed primarily of skeletal debris derived from sites of accumulation of the Wolayer facies [Dullo 1992; Schonlaub and Histon, 2000]. The Uggwa limestones exposed in the stratigraphic section at Cellon (fig. 2) are made up of 1-3 mm thick graded beds [see Ferretti and Schonlaub, text-fig. 4]. Each bed is a debris flow that spread out across a thin mat of organic material that had formed on the surface of the preceding flow. Coarse-grained crinozoan and bryozoan fragments comprise most of the material at the base of each layer [Dullo, 1992]. A few straight-shelled nautiloids occur at the base of some of the layers. The spacing of septa in these nautiloid shells suggests deposition on a deep shelf [K. Histon, oral commun., 2001]. Other Uggwa limestone sequences, such as those at Valbertad, Refugio Nordio on Uggwa stream, Hoher Treibe, and the Feistritz graben in the Karawanken (see fig. 1) are closely similar lithically to that in the Cellon section. *A. ordovicicus* conodonts have been recovered from one stratigraphic level in the upper part of the Uggwa at Cellon [Ferretti and Schonlaub, 2001, p. 8]. Similar conodont faunas have been recorded from the Uggwa limestones in sections on the Italian side of the Carnic Alps by Serpagli [1967] [see discussion in Ferretti and Schonlaub, 2001]. W. Hamman collected brachiopods and trilobites from the lower part of the Uggwa Limestones at Cellon (see fig. 2). He (W. Hamman written report to Schonlaub, 2001) suggested that these faunas may be Rawtheyian in age. Collections made in 2000-2001 by Schonlaub, Hamman, Storch and the author from the upper part of the Uggwa in the Cellon section and probable coeval layers at Hoher Triebe and the Feistritz graben yielded *P. persculptus* and *Mucronaspis*.

Dullo [1992, p. 326] compared the Carnic Alps late Ordovician limestones with Paleozoic limestones that had developed in both tropical and non-tropical sites. He pointed to the absence of certain types of algae, corals and stromatoporoids and the prominence of bryozoans and crinozoans which, he concluded, suggested that these limestones formed in cool water environments. He based this conclusion on an analysis of Paleozoic cool water limestones described by James [1997].

The Plocken Formation, which overlies Uggwa limestones in the Plocken facies, bears *Hirnantia* fauna brachio-



pods [Schonlaub, 1988, p. 109]. *A. ordovicicus* zone conodonts were recorded from three stratigraphic levels within the Plocken Formation [Ferreti and Schonlaub, 2001, p. 9-10]. Priewalder [1997] cited chitinozoans suggestive of the Hirnantian from the Plocken Formation. Schonlaub [1988, p. 109] described the Plocken strata as "being characterized by internal erosion surfaces, small-scale channeling, reworking of sediment, bioturbation with subsequent infilling of fossils, and pronounced load deformation structures." Quartz sand layers and lenses are relatively common within the Plocken in the Cellon section. The Upper Llandovery (*Amorphognathoides* conodont zone) Kok Formation occurs in limestones superjacent to the Plocken Formation.

Occurrences of *Hirnantia* faunas in the Plocken strata and *P. persculptus* and *Mucronaspis* in the upper beds of the subjacent Uggwa Formation indicate correlation with the *persculptus* Zone. The presence of probable Rawtheyian faunas in the lower layers of the Uggwa Limestones and the stratigraphic continuity within the Uggwa Limestones suggests that some of these limestones were deposited during the *extraordinarius* Zone. These correlations suggest that the Uggwa limestones – Plocken Formation sequence was deposited during the late Ordovician glacial interval. The upper part of the Plocken Formation seems to have formed during the early phases of deglaciation and consequent sea level rise at which time the site of accumulation was swept by storm-generated waves. The deglaciation interval was followed by tectonism that resulted in exposure of the shelf.

## THE NEVADA SUCCESSION

The Carnic Alps late Ordovician conodont, graptolite and chitinozoan faunas allow relatively precise correlations to be made with the Nevada succession as described by Finney *et al.* [1997, 1999] because certain of the same chitinozoan, conodont and graptolite taxa are present in both areas. The Nevada late Ordovician faunal and stratal successions span the glacial interval as do the coeval successions in the Carnic Alps. Coincidentally, tectonism of both the platforms on which each succession accumulated at about the same time soon after deglaciation.

### Slope facies

The Vinini Creek late Ordovician strata (see figs. 3, 4) formed on a slope forming the margin of the Laurentian platform. The Vinini succession bears *Dicellograptus complanatus ornatus*, *Paraorthograptus pacificus*, *Normalograptus extraordinarius* and *Persculptograptus persculptus* zone graptolites, *A. ordovicicus* zone conodonts, and certain chitinozoans similar to those in the Plocken Formation [Finney *et al.*, 1999; Sweet, 2000; Soufiane and Achab, 2000].

The upper part of the *pacificus* graptolite zone in the Vinini Creek section lies within a 9 meter thick unit of dark gray to black, organic-rich mudstone (20-30 percent total organic carbon) with hydrogen-rich kerogen. These strata probably accumulated under an oxygen minimum zone [see Finney *et al.*, 1999]. Strata in the uppermost *pacificus* zone change gradationally upward into brown mudstones which have less organic content than the subjacent black mudstones. The brown mudstones are replaced slightly higher stratigraphically by light gray lime mudstones that contain

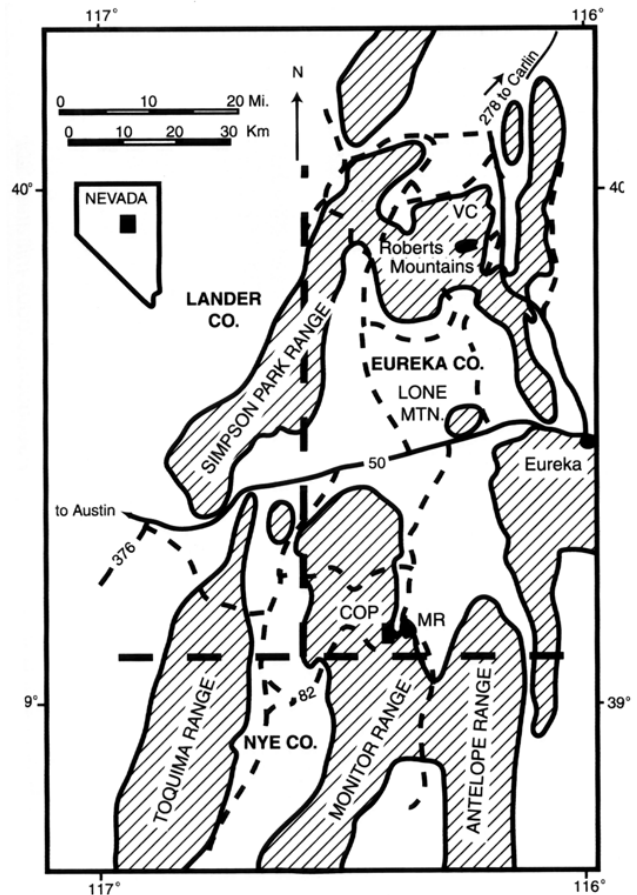


FIG. 3. – Map of central Nevada indicating locations of the late Ordovician stratigraphic sections noted in text : Vinini Creek (VC) (shelf slope); Monitor Range (MR – section at Copenhagen Canyon – COP) (Outer shelf); Lone Mountain (Inner shelf).

FIG. 3. – Carte du Nevada central et localisation des coupes stratigraphiques de l'Ordovicien terminal indiquées dans le texte : Vinini Creek (VC) (talus de plate-forme) ; Monitor Range (MR – coupe à Copenhagen Canyon – COP) (plate-forme externe) ; Lone Mountains (plate-forme interne).

*Normalograptus extraordinarius* and other normalograptids. These lime mudstones probably formed during sea level lowstand when carbonate sediments that formed on the shelf slumped downslope. The superjacent layers are thinly-laminated, yellow-weathering gray limestones that bear *Persculptograptus persculptus* and normalograptids. These *P. persculptus* – bearing limestones were deposited as debris flows during deglaciation and sea level rise. The same Vinini Formation strata that contain *pacificus*, *extraordinarius*, and *persculptus* zone graptolite faunas also bear *Amorphognathus ordovicicus* zone conodonts [Sweet, 2000] and chitinozoans suggestive of the Hirnantian Stage [Finney *et al.*, 1999; Soufiane and Achab, 2000]. Llandovery (*convolutus* zone) graptolites occur in shales that lie disconformably above the *P. persculptus*-bearing beds.

### Shelf facies

The Monitor Range late Ordovician strata (fig. 3) were deposited in an embayment on the outer part of the same Laurentian plate shelf on which Vinini succession strata accumulated. The lower part of the Hanson Creek Formation in the Monitor Range sequence bears *pacificus* zone

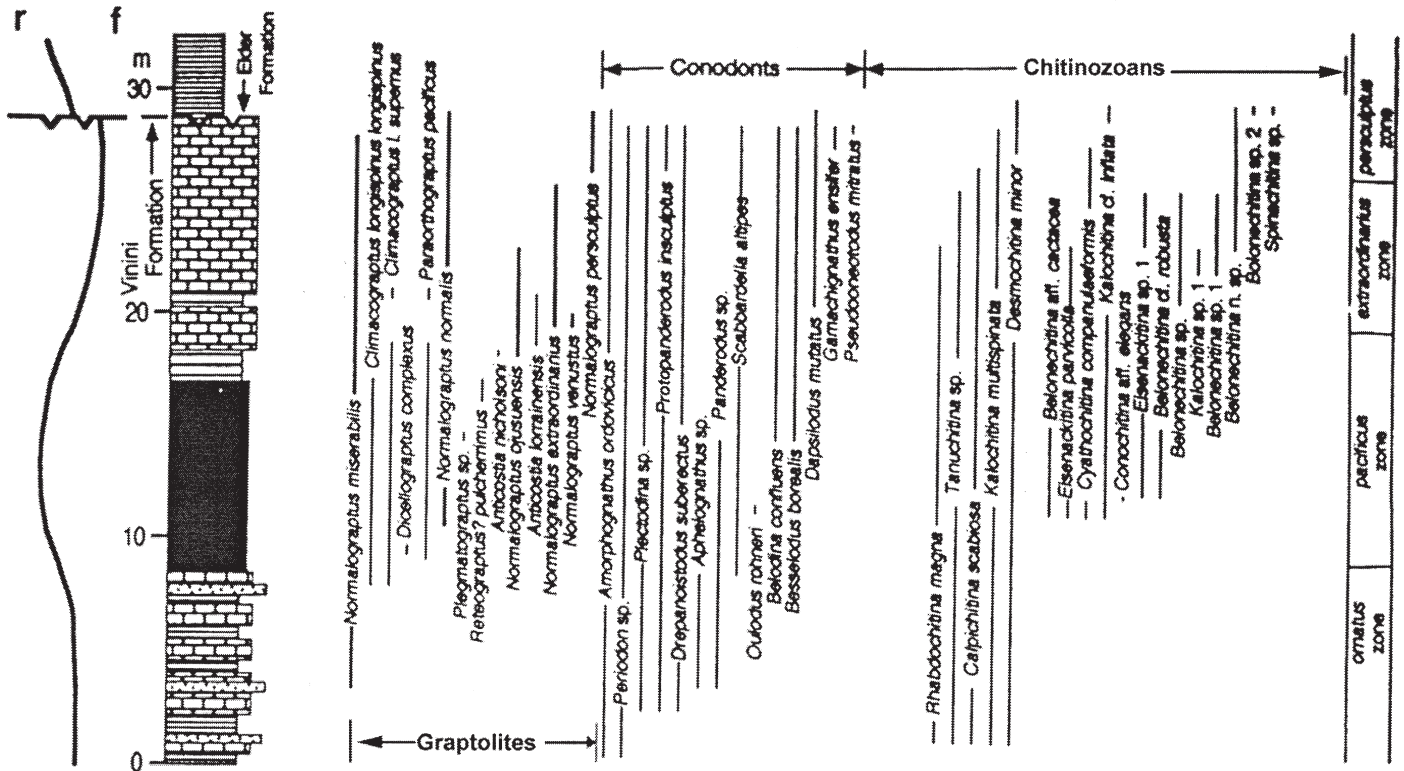


FIG. 4. – Vinini Creek Late Ordovician stratigraphic and faunal successions and suggested sea level change (r = rising and f = falling). Lithologic features are described in text.

FIG. 4. – Successions stratigraphiques et fauniques de l'Ordovicien terminal de Vinini Creek et proposition des fluctuations du niveau de la mer (r = montée et f = chute). Les caractères lithologiques sont décrits dans le texte.

graptolites in a monotonous succession of thin-bedded, gray lime mudstones that also bear conodont, chitinozoan and radiolarian faunas [Finney *et al.*, 1999]. *A. ordovicicus* zone conodonts in the succession range from *P. pacificus*-bearing strata through strata considered to be coeval with the *extraordinarius* zone. Rapid vertical facies change from thin-bedded limestones to medium-bedded, gray, cross-stratified lime grainstones and oolitic dolograins signify marked shallowing in the depositional site within rocks considered coeval with the *extraordinarius* zone [Finney *et al.*, 1999]. The interval of shallowing is accompanied by a change in siliceous sponge spicules from assemblages of relatively deep water hexactinellid-dominated assemblages to lithistid-dominated associations that are indicative of shallow subtidal conditions [Noble in Finney *et al.*, 1999]. The oolitic dolograins are overlain by 1 to 6 cm of orange-brown, fine-grained quartz arenite which was derived from incision into shelf strata. The quartz arenite occurs as a veneer across an irregular surface which is within the lower part of the *persculptus* zone. The surface is considered indicative of maximum sea-level lowstand during late Ordovician glaciation [Finney *et al.*, 1999, p. 216]. The Monitor Range late Ordovician environmental record indicates that the *extraordinarius* zone and lower part of the *persculptus* zone was the time of low to lowest sea levels, a determination consistent with that of Sutcliffe *et al.* [2000] in higher latitude sites.

Several meters of medium gray lime wackestone with dolomitized borrows occur stratigraphically above the quartz arenite. This shallow subtidal facies is followed abruptly by a thick succession of dark gray lime mudstone

with abundant chert modules and stringers. These chert-rich limestones bear conodonts, chitinozoans and graptolites indicative of the early Llandovery and were deposited as sea level rose during deglaciation [see Finney *et al.*, 1999; Sweet, 2000].

The Lone Mountain late Ordovician carbonate sequence (fig. 3) is representative of the inner shelf on which shallow marine environments were prevalent. Carbonates within this succession bear conodonts coeval with those of the *A. ordovicicus* zone. Carbonate deposition in this inner shelf area ended early in the glacial interval. Karsts developed across the carbonates during the glacial interval [Finney *et al.*, 1999; Sweet, 2000].

## SUMMARY

Correlation of the mid-latitude late Ordovician Carnic Alps-Karawanken successions with the coeval tropical Nevada sequences suggests that onset and decline of glaciation led to significant environmental changes in both areas. In the Nevada successions, upwelling at the shelf margin ceased as sea-level fell during onset of glaciation and shallowing of shelf environments. During the early part of the glacial interval, shallow or inner shelf environments in both the Carnic Alps and Nevada were the source of materials that were carried as slumps and debris flows into deeper shelf and slope sites. Subsequently, inner shelf environments in both areas were exposed as sea level fell. Karsts developed across both areas during the latter phases of glaciation. Carbonate sediments accumulated in both the

Carnic Alps and Nevada deep shelf environments throughout the glacial interval. Quartz sands spread widely in deep shelf environments in both areas during early phases of deglaciation. *P. persculptus* zone sediments on shelves in both areas reflect the influence of storm activity during deglaciation. Perhaps coincidentally, shelves in both areas were subjected to tectonism resulting in uplift and exposure as the glacial interval ended.

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