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On the Upper Ordovician unconformity in the Pyrenees: New evidence from the La Cerdanya area

J.M. CASAS [1] **and O. FERNÁNDEZ** [2]

[1] **Departament de Geodinàmica i Geofísica, Universitat de Barcelona**
Martí i Franquès, s/n, 08028 Barcelona. E-mail: casas@ub.edu

[2] **Midland Valley Exploration**
1767A Denver West Blvd., Golden, Colorado 80401

ABSTRACT

In recent years, contradictory reports about whether or not an unconformity exists at the base of the Upper Ordovician succession of the Pyrenees have been made. In the Cerdanya area (Central Pyrenees), good outcrop evidence for this unconformity is displayed at the base of the Rabassa conglomerates. In this area, the Upper Ordovician rocks overlie a tilted Cambro-Ordovician sequence, displaying an angular unconformity and indicating a break in the stratigraphic series. Moreover, the existence of such an unconformity is supported by the distribution of Variscan minor structures, suggesting that the Cambro-Ordovician and the Upper Ordovician strata initially had different orientations before the main Variscan folding.

KEYWORDS **Upper Ordovician. Angular unconformity. Variscan. Pyrenees.**

INTRODUCTION

The occurrence in the Pyrenees of an Upper Ordovician unconformity has been widely discussed since the work of Llopis Lladó (1965). This author invoked late Caledonian movements to explain an angular unconformity between the Upper Ordovician conglomerates and the underlying Cambro-Ordovician series, south of Andorra, in the Rabassa dome (Fig. 1). Santanach (1972), on the basis of cartographic data, describes the basal Upper Ordovician conglomerates that overlie different levels of the Cambro-Ordovician rocks, to the west of the Canigó massif. This author points out a pre-Caradocian regional uplift and fracturing, together with intense erosion, as a cause of the unconformity.

However, the presence of this unconformity has not been accepted by all authors. Hartevelt (1970) does not observe this unconformity and, at the base of the Upper Ordovician conglomerates, describes very local erosion channels instead. Furthermore, in the Orri dome (Fig. 1), Speksnijder (1986) does not find convincing evidence for an Upper Ordovician unconformity.

On the other hand, data in favour of the existence of the unconformity, based on the different attitudes of Variscan minor structures in both, the Upper Ordovician and the underlying Cambro-Ordovician series, have been obtained by Santanach (1972) and Muñoz and Casas (1996) in the Rabassa dome and Canigó massif, and by Den Brok (1989) in the Lys-Caillouas massif.

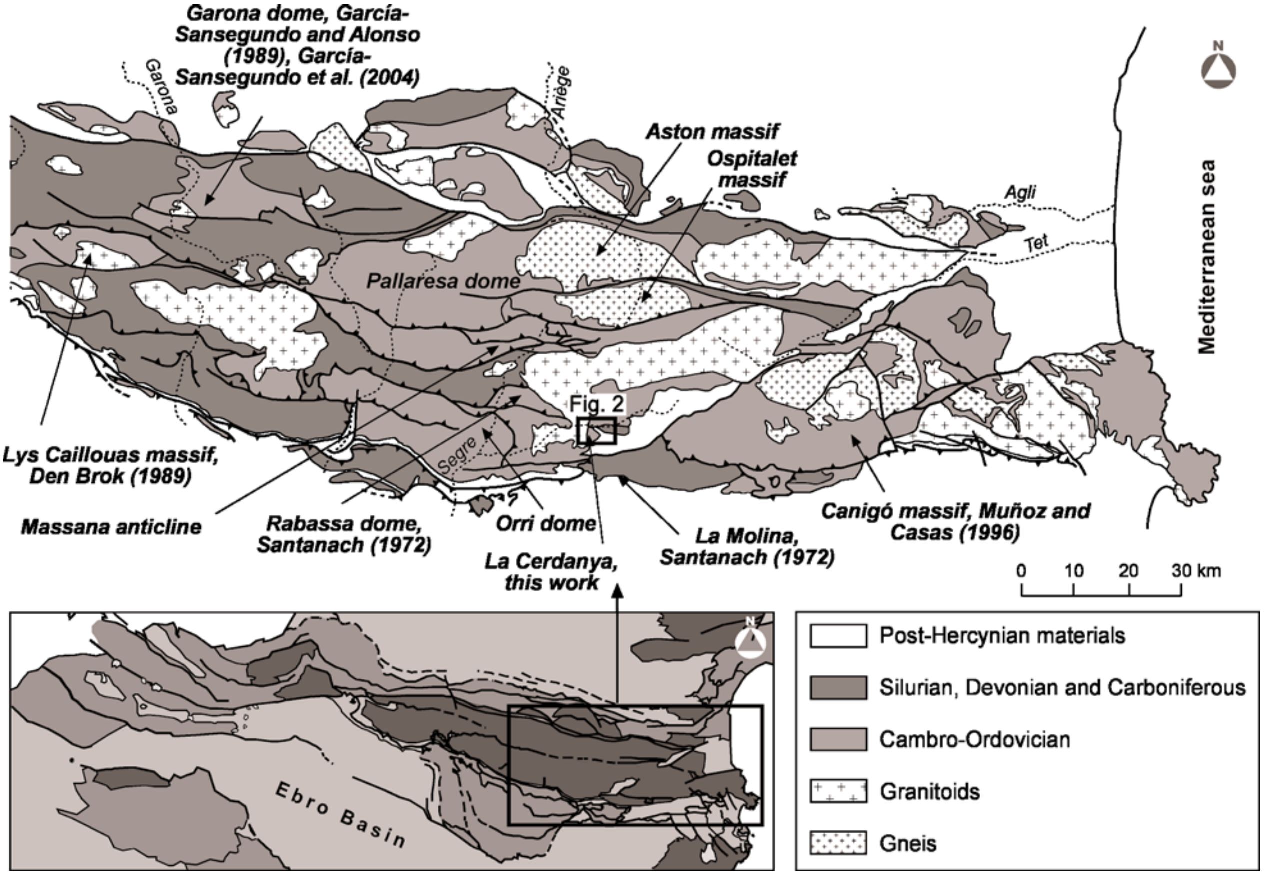

FIGURE 1 | **Simplified geological map of the Variscan Pyrenees. The box shows the location of the study area. The sites where the Upper Ordovician unconformity has been described are indicated.**

Recent research on the Paleozoic of the Pyrenees has provided new evidence for the Upper Ordovician unconformity. Based on stratigraphic correlations Laumonier (1988) suggests the presence of an important unconformity in the Pallaresa, Aston and Ospitalet massifs. Further west, in the Garona dome (Fig. 1), stratigraphic and field evidence of the Upper Ordovician unconformity has been obtained by García-Sansegundo and Alonso (1989) and by García-Sansegundo et al. (2004).

In this paper we present the results of new geological mapping in the Central Pyrenees, affording outcrop and structural evidence that confirms the presence of an angular unconformity between the Upper Ordovician sediments and the underlying Cambro-Ordovician succession.

REGIONAL SETTING

The area in which we describe the unconformity constitutes the eastward continuation of the Rabassa dome, separated from the western part by the Andorra-Mont Lluís granodiorite. Paleozoic succession ranges from the Cambro-Ordovician to the Upper Carboniferous (Fig. 2). Cambro-Ordovician, Upper Ordovician, Silurian and Carboniferous strata consist mainly of siliciclastic sediments, whereas Devonian strata are mainly made up of limestones.

The oldest rocks are made up of a thick azoic succession of rhythmic alternation of siltstones and argilites that can be correlated with the Jujols Series defined by Cavet (1957) in the northern part of the Canigó massif, forming part of the Jujols Formation of Laumonier (1988). Although these sediments are often regarded as Cambro-Ordovician, a Middle/Late Cambrian (Abad, 1987, 1988; Laumonier, 1988) or Late Cambrian/Early Ordovician age (Guitard et al., 1988) has been proposed for the Jujols Series.

In the vicinity of this area, Hartevelt (1970) divided the Upper Ordovician succession into five formations. From oldest to youngest, Rabassa Conglomerate, Cava, Estana, Ansovell and Bar Quartzite Formations. With some variations in thickness and lithology, Hartevelt's division can be identified in most Upper Ordovician successions across the Pyrenees and the northern part of the Catalan Coastal Ranges (Cavet, 1957; Barnolas and García-Sansegundo, 1992). Nevertheless, a remarkable presence of volcanic and volcano-sedimentary rocks can be noted in the Freser and Ter valleys areas (Robert and Thiebaut, 1976; Martí et al., 1986).

The Rabassa Conglomerate constitutes the lowest part of the Upper Ordovician succession, and is made up of a sequence of conglomerates and microconglomerates that show extreme lateral thickness variations from a few to 200 m. The conglomerates are overlain by the sandstones of the Cava Formation. In the study area the Cava Fm varies in thickness from 100 to 800 m and occasionally pass laterally to the Rabassa conglomerates. Although scattered, brachiopods, are locally abundant in the Cava Fm. The Estana Fm lies above the Cava Fm and consists of limestones and marly limestones. When present, the Estana Fm constitutes a good stratigraphic key level and corresponds to the "schistes troués" or "Grauwacke à Orthis" and the "Caradoc limestones" of French and Dutch geologists, respectively. Fossils are relatively abundant within this Formation. The Ansovell Fm overlies the Estana limestones and is made up of dark shales and siltstones with minor interbedded quartzite layers in the uppermost part. In cases where the Estana Fm tapers off, the shales of the Ansovell Fm directly ovelie the sandstones of the Cava Fm. The Bar Fm, located at the top of the Upper Ordovician succession, consists of a 5 to 10 m thick quartzite layer that overlies the Ansovell Fm.

Hartevelt (1970) attributed the Rabassa conglomerates and the sandstones of the Cava Fm to the Caradoc, the Estana Fm to the Caradoc-Asghill, and the Bar quartzite to the Asghill, although Gil-Peña et al. (2001) suggest that the Ordovician Silurian boundary can be located within this quartzite.

All these series are affected by the Variscan crustal shortening event, developed during Namurian and early Westphalian times in the Central Pyrenees. In the Cambro-Ordovician and Upper Ordovician rocks of the study area, two main folding episodes (D1 and D2) with axial planar crenulation cleavages (S1 and S2) can be recognized. D1 are E-W oriented north verging folds, with subvertical axial surfaces related to subvertical S1 planes. D2 are south verging folds with axial surfaces dipping moderately to the north. The S2 cleavage develops, dipping moderately to the north with intersection lineations (L2)

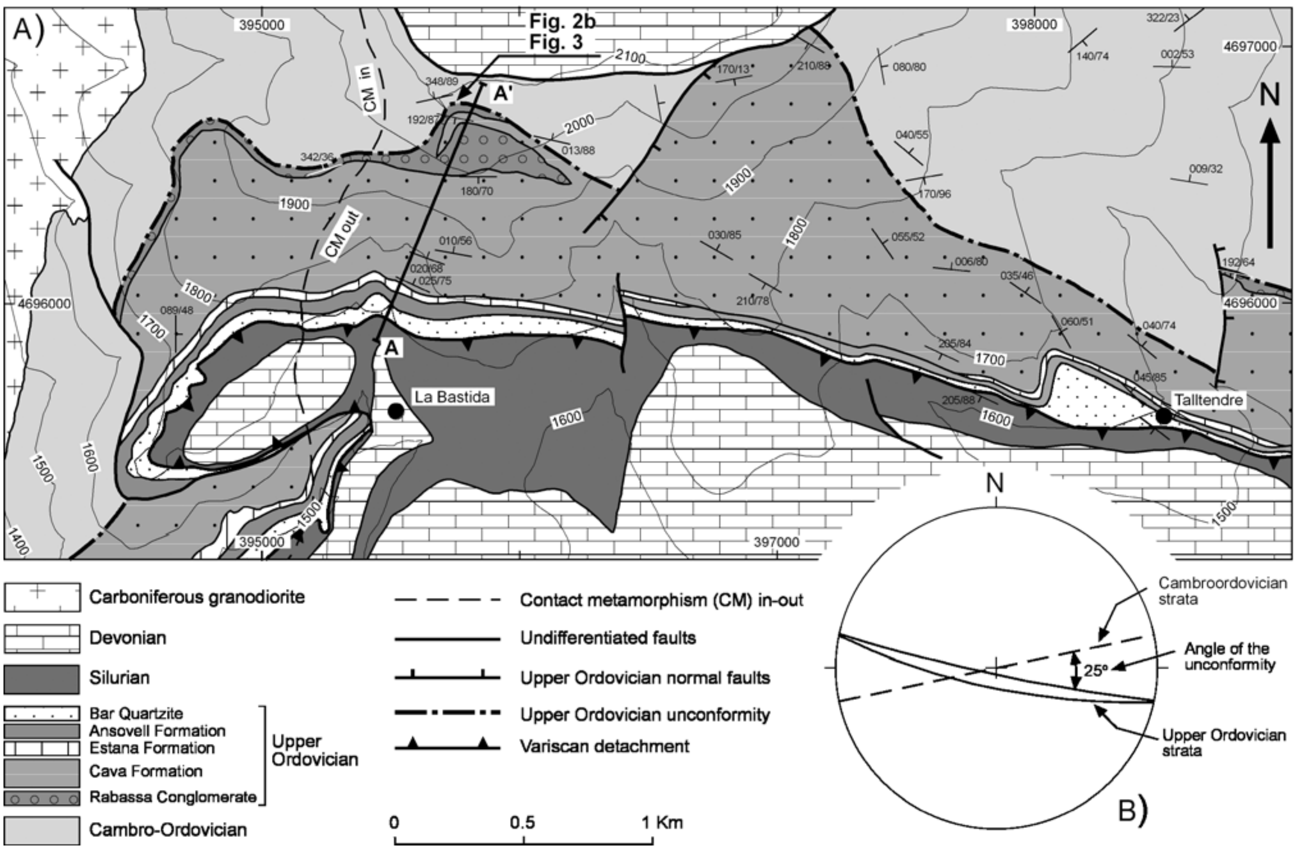

FIGURE 2 | **A) Geological map of the study area highlighting the location of the outcrop where the Upper Ordovician unconformity can be observed (Figs. 2B and 3). The line A-A' indicates the location of Figure 4. B) Equal-area lower hemisphere stereoplot showing the geometry of the unconformity.**

oriented E-W homoaxial with L1. The general structure of the zone can be interpreted as a superposition of hectometric sized D2 folds onto a kilometric sized normal limb of a D1 fold. Further to the west, the D2 hinge forms the southern slope of the La Rabassa dome. Although not recognized in this area, some authors (Cirés et al., 1990; Poblet, 1991; Capellà and Bou, 1997; Laumonier, 2004) report the presence of large scale pre-cleavage folds in the infra-Silurian rocks of the Rabassa dome and the Massana anticline.

In the overlying Silurian, Devonian and Carboniferous successions, south directed thrust sheets, mainly merging into the Silurian black shales, are the most prominent Variscan contractional structures (Hartevelt, 1970; Casas et al., 2004).

All these structures, D1/D2 folds, cleavage and thrusts, are affected by at least two large scale open fold systems. The folds display a roughly E-W orientation with axial surfaces that are subvertical or are strongly dipping to the south. An Alpine age cannot be discarded for one of these fold systems.

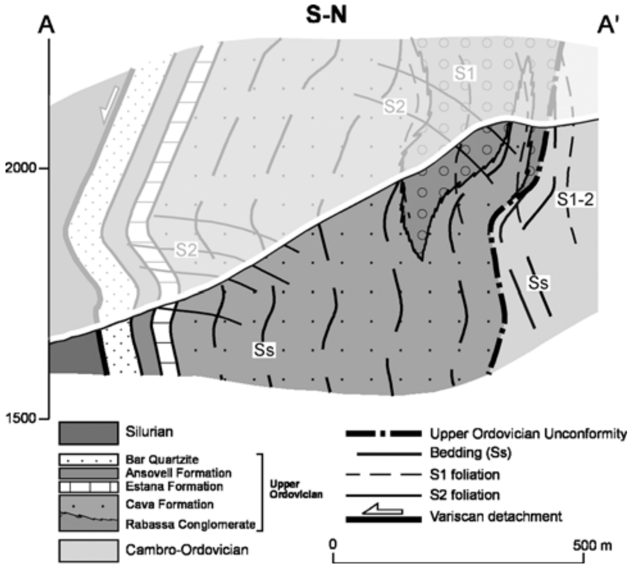

FIGURE 4 | **Cross-section of the studied area, illustrating the Variscan structure and the angular character of the Upper Ordovician unconformity. For the location of the cross-section refer to Figure 2.**

THE UPPER ORDOVICIAN UNCONFORMITY

Outcrop evidence

The unconformity is well exposed north of Bellver de Cerdanya, not far from the locality of la Bastida (Fig. 2). The Cambro-Ordovician sediments are truncated and unconformably overlain by the Rabassa conglomerates (Fig. 3). Cambro-Ordovician strata are tilted with respect to the Upper Ordovician succession and the unconformity angle is approximately 25° (Figs. 2 and 4). Where the Rabassa conglomerates are absent the sandstones of the Cava Fm formation unconformably overlie the Cambro-Ordovician.

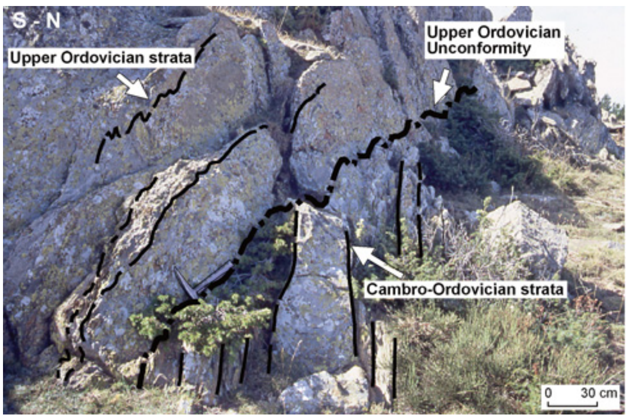

FIGURE 3 | **Photograph and sketch of the Upper Ordovician unconformity. Note the angle of the unconformity and the cutting character of the Rabassa conglomerates in the underlying Cambro-Ordovician strata. The location of this Figure is indicated in Figure 2.**

A set of extensional faults affect the sediments of the Cava and Rabassa Conglomerate formations and the Cambroordovician rocks (Fig. 2). At present, faults are steep exhibiting a broadly N-S cartographic trace with maximum throws of about 0.2 to 0.9 km. Displacement progressively diminishes upwards and dies out in the Cava rocks. The Rabassa Conglomerate and the lower part of the Cava formations are the syn-tectonic sediments, whereas the upper part of Cava Fm and the sediments of the Estana, Ansovell and Bar Fms are the post-tectonic sediments. It should be noted that as the Upper Ordovician unconformity is cut by these normal faults, significant pre-Upper Ordovician erosion must have occurred before the normal faulting event.

Structural evidence

In the study area, D1 and D2 related structures developed differently in the Upper Ordovician and Cambro-Ordovician successions. It is not easy to distinguish S1 from S2 in the Cambro-Ordovician, and the most conspicuous Variscan structures are a S1-2 composite crenulation cleavage and a L1-2 intersection lineation. The L1-2 lineation is dispersed on a NE gently dipping plane (Fig. 5A). The L1 lineation was identified in very few cases and is consistently NE-SW oriented.

In contrast, in the Upper Ordovician rocks, S1 and S2 although irregularly developed, are clearly distinguish-

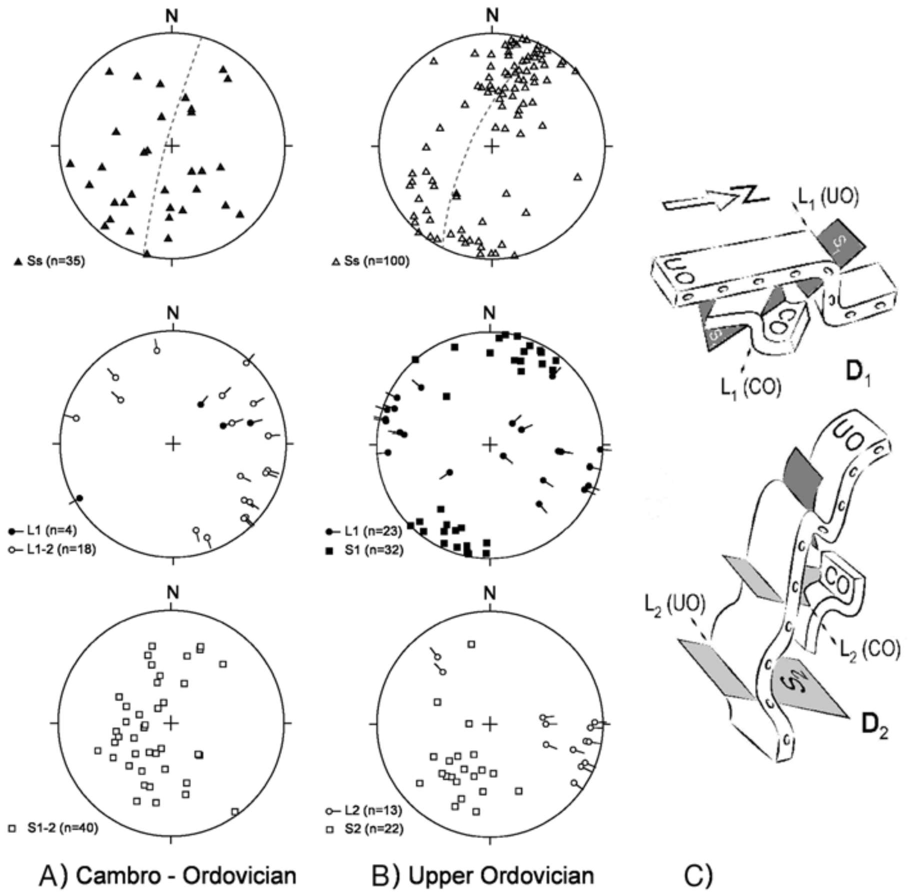

FIGURE 5 | **A) and B) Equal-area lower hemisphere stereoplots of the Variscan mesostructures and bedding (Ss) from the Cambro-Ordovician and Upper Ordovician, respectively. C) Sketch displaying the different attitudes of the Variscan structures in the Cambro-Ordovician (CO) and Upper Ordovician (UO) rocks**

able. S1 is subvertical, whereas S2 dips moderately to the NE. L1, L2 and the D2 minor fold axis are practically homoaxial, roughly ESE-WNW oriented (Fig. 5B).

The different orientation of the D1 fold axis in the Upper Ordovician and Cambro-Ordovician series could be attributed to the folding of two oblique surfaces, the Cambro-Ordovician and the Upper Ordovician strata. Irregular development of structures prevent us from restoring the effect of the D1 and D2 folds and thus pinpoint the initial orientation of the Cambro-Ordovician beds under the unconformity. However, a NNE-SSW initial orientation of the Cambro-Ordovician beds, gently dipping to the east, can account for the formation of D1 minor folds, oriented NW-SE and dipping to the SE. In contrast, in the initially horizontal Upper Ordovician rocks, D1 minor folds originate with a subhorizontal ESE-WNW attitude. This can account, for the different axial stability of D2 minor folds in both series. The high angle between the D2 axial sufaces (S2) and the L1 fold axes could explain the low axial direction stability of the D2 minor folds in the Cambro-Ordovician sediments (Fig. 5). However, the D2 minor folds exhibit a fairly constant ESE-WNW orientation in the Upper Ordovician rocks.

DISCUSSION AND CONCLUSIONS

The area displays outcrop evidence of the angular unconformity between the Upper Ordovician sediments and the underlying Cambro-Ordovician series. Cambro-Ordovician strata are tilted with respect to the Upper Ordovician succession, defining two obliquely inclined successions separated by the unconformity.

Outcrop, cartographic and structural evidence for the Upper Ordovician unconformity is scattered across the Central and Eastern Pyrenees, indicating that the unconformity has a regional character (Fig. 1). The unconformity can be attributed to the uplift, tilting and erosion of the Cambro-Ordovician series prior to the deposition of the Upper Ordovician conglomerates and sandstones (Santanach, 1972; García-Sansegundo et al., 2004). Tilting and truncation of the Cambro-Ordovician strata suggest a tectonic uplift, perhaps together with a drop in the eustatic sea level.

Further work is needed to confirm the hypothesis of Sansegundo et al. (2004) that the tilting of the Cambro-Ordovician succession could be related to an Upper Ordovician extensional episode. In the study area, the unconformity is clearly displaced by the Upper Ordovician normal faulting episode. In such a case, pre-Upper Ordovican tilting of the Carbro-Ordovician strata and hence the origin of the unconformity could probably be due to an older, Early-Mid Ordovician (?) deformation event.

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