Antler orogeny: A Mediterranean-type orogeny

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ABSTRACT

The late Cenozoic thrust belts of the Apennine, Carpathian, and Hellenic systems of the Mediterranean region provide modern analogues for the middle Paleozoic Antler orogeny. Each of these young or active mountain belts formed in convergent systems in which thrusting occurred behind a zone of trench retreat, while a region of extension developed contemporaneously within the hanging wall of the subduction systems. Dynamic models that have been recently developed for these tectonic systems provide a basis for interpretation for the Antler belt. Many, if not all, of the geologic relations observed in the Antler belt, including the lack of a collided arc and subsidence of a broad extensional region behind the thrust belt, are also present within these young Mediterranean thrust-belt systems. If this interpretation is correct, then the entire Antler belt may have been preserved, with no need for other tectonic elements to have been present west of the Antler thrust belt and the Havallah basin.

INTRODUCTION

A wide range of tectonic settings has been suggested to explain the middle Paleozoic Antler orogeny in the Cordillera of the western United States; in a review of the Antler orogeny, Nilsen and Stewart (1980) indicated that at least ten different models have been proposed. This lack of consensus among geologists working on the Antler belt has arisen partly from the failure of any of these models to account for all aspects of the orogen. Each of the tectonic settings that has been proposed to date conflicts with geologic observations from the Antler belt in one way or another. In particular, many workers have suggested that the Antler orogeny is related to an arc-continent collision (e.g., see Speed et al., 1988), but invoking such a tectonic setting leaves many important geologic relations unexplained, such as the recognition of a collided arc.

Herein we suggest that modern analogues to the Antler belt can be found in some of the young thrust-belt systems of the Mediterranean region and argue that these thrust-belt systems, which are closely associated with back-arc extension behind the thrust belt, display most if not all of the geologic relations observed in the Paleozoic Antler orogen. Whereas similar tectonic settings may exist in other parts of the world, such as in the southwest Pacific, we use the Apennine system as the best documented system analogous to the Antler.

GENERAL GEOLOGY OF THE ANTLER OROGEN

Middle Paleozoic deformation is known along the Cordilleran margin of North America, but we confine our discussion of the Antler orogenic belt to that part of the belt that extends from southern Idaho to central Nevada (Fig. 1). This part of the belt was the first to be defined as the Antler orogen (Roberts et al., 1958) and is the best studied part of the Antler belt. Within this zone, the Antler orogenic belt consists of a complex imbricated sequence of Cambrian to Upper Devonian continental-margin, slope and rise sedimentary rocks emplaced eastward onto a lower Paleozoic shallow-water shelf assemblage above the Roberts Mountains thrust fault (Roberts et al., 1958; Kay and Crawford, 1964; Turner et al., 1989). The upper plate of the Roberts Mountains thrust is everywhere in fault contact with the shelf assemblage. Transitional facies and sedimentologic and faunal ties between the two assemblages suggest that the rocks of the Roberts Mountains allochthon were probably deposited west of the footwall shelf assemblage (see Turner et al., 1989). Tectonic overlap of the two assemblages is currently about 140 km, but removal of Cenozoic extension would reduce the overlap to probably less than 100 km. The present eastward convexity of the orogenic belt is probably original (Oldow, 1984), but continuation of the belt to the north and south is largely unknown because it has been disrupted and overprinted by younger tectonic and magmatic events.

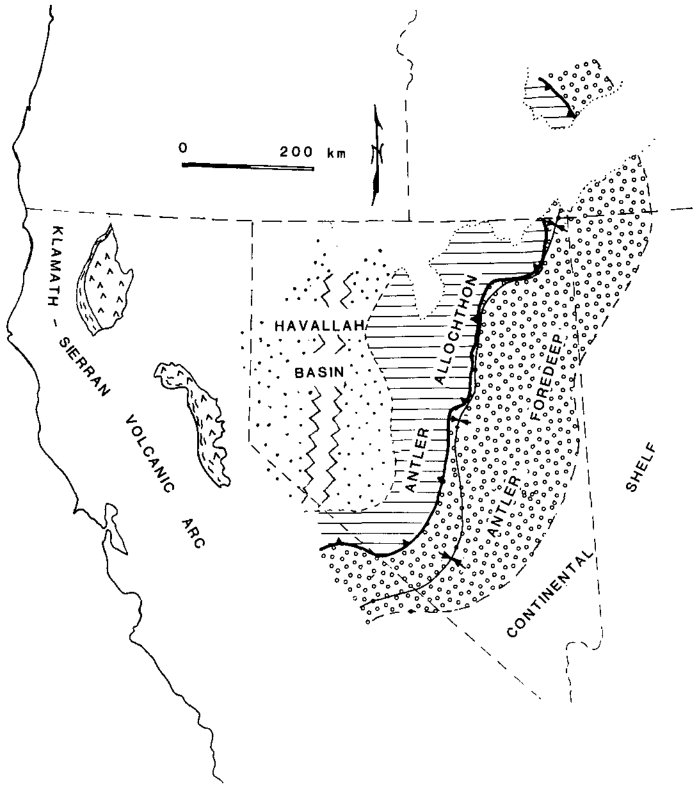

Figure 1. Generalized tectonic map of Antler allochthon and related tectonic units of west-central United States. Tectonic units shown in their present position except for Havallah basin, which has been restored to position west of Antler belt. Separation in Havallah basin indicates uncertainty in original width and position of some of its western parts. Inverted V pattern shows present position of Klamath-Sierran volcanic arc. Dashed lines are Middle Devonian metamorphic rocks.

The allochthon was emplaced over a period of about 8–10 m.y. in Early Mississippian time (Johnson and Pendergast, 1981; Sandberg et al., 1983; Miller et al., 1984). During and subsequent to its emplacement, the allochthon formed a highland and was the source for a well-developed foredeep sequence to the east (Fig. 1; Poole, 1974; Dickinson et al., 1983). In Late Mississippian and Pennsylvanian time, the allochthon was progressively worn down and covered by a shallow-water overlap assemblage (Roberts et al., 1958; Miller et al., 1984). Thus the Antler orogenic belt consists of a complex allochthon of lower Paleozoic continental slope and rise sedimentary rocks that was thrust eastward over a contemporaneous shelf and foredeep basin sequence.

West of the Antler highlands, the Havallah sedimentary assemblage was deposited during the late Paleozoic in deep water, probably partly on oceanic crust (Miller et al., 1984). Rocks of the Havallah assemblage were partly derived from the Roberts Mountains allochthon to the east and, in its younger part, from a volcanic arc to the west (Miller et al., 1984). The Havallah assemblage is thus best interpreted to have been deposited in a marginal basin west of the Antler orogenic belt. In Permian (Silberling and Roberts, 1962) or possibly Early Triassic time, the Havallah rocks were emplaced eastward above the Roberts Mountains allochthon and their overlap assemblage.

A complex Paleozoic volcanic arc assemblage in the northern Sierra Nevada and Klamath Mountains was active intermittently in early and late Paleozoic time. The polarity of the arc in early Paleozoic time is not well established, but Silurian blueschist and a melange of oceanic rocks of early Paleozoic age west of the arc, and Middle Devonian west-vergent thrusts associated with metamorphism west of the Klamath-Sierran arc, suggest that early Paleozoic subduction of oceanic lithosphere was eastward beneath the arc (Davis, 1968; Burchfiel and Davis, 1972, 1975). Late Devonian–Early Mississippian magmatism in the arc was contemporaneous with emplacement of the Antler allochthon. The position of the arc relative to the North American continental margin is not known, but sedimentary rocks within the basal part of the arc have a continental source, and quartzite and arkosic rocks in this sequence have similarities to rocks in the Roberts Mountains allochthon (Schweickert and Snyder, 1981). Although the data are few, we can interpret that in early Paleozoic time the Klamath-Sierran arc, or its lateral extension, was west of North America and the Antler assemblage.

Within this simplified framework, the data that we consider most important in establishing the tectonic setting for the Antler orogen include the following. (1) The foredeep clastic rocks contain no debris derived from a volcanic arc (Dickinson et al., 1983). (2) The Antler orogenic belt consists only of an imbricated sequence of continental margin sedimentary rocks that contain only very rare contributions from a volcanic arc. (3) The Antler orogenic belt was not associated with plutonism or high-grade metamorphism. Greenschist facies metamorphic rocks are present in the Osgood Mountains within rocks of the Antler transitional assemblage (Fig. 1)—these metamorphic rocks are unconformably overlain by Pennsylvanian sedimentary rocks that are part of the Antler overlap assemblage, suggesting that lower structural levels of the Antler orogen were metamorphosed to low grade in its western part and that these rocks were exposed shortly after emplacement of the allochthon (Hotz and Wilden, 1964). (4) The oldest rocks in the Havallah basin, the basal Schoonover Formation, are known to be as old as Famennian (Late Devonian) and are thus older than the emplacement of the Roberts Mountains allochthon (Miller et al., 1984). (5) Mississippian rocks in the lower part of the Havallah basin (Schoonover and Goughs Canyon Formations) contain a significant amount of basaltic volcanic rocks, probably erupted during extension (Miller et al., 1984). (6) The Middle Devonian deformational event within the Klamath-Sierran arc ended at about 375 Ma (Schweickert et al., 1984), about 15 m.y. before the emplacement of the Roberts Mountains allochthon. (This deformation appears to be associated with west-vergent thrusting that may have been synthetic to the subduction beneath the arc [Davis, 1968; Burchfiel and Davis, 1981].) (7) Following Middle Devonian deformation within the arc, there was a major burst of volcanism in Late Devonian and Early Mississippian time, which was partly contemporaneous with the Antler orogeny (Harwood, 1988).

We believe that the paleogeography and geologic framework of the Antler orogenic belt, as outlined above, do not support an arc-continent collision, which is perhaps the most commonly accepted interpretation for the Antler orogeny (e.g., see Moores, 1970; Speed and Sleep, 1982). Important relations observed in the Antler belt that are unexplained by arc-continent collision include (1) the arc that was west of North America and its structures appears to be west facing, not east facing; (2) deposition of sediments in the Havallah basin began before and continued during the emplacement of the Roberts Mountains allochthon; (3) deposition occurred in a paleogeographic position that should have been occupied by the collided arc; and (4) the Antler foredeep contains no volcanic material.

In the following section we suggest that the paleogeography and geologic relations observed within the Antler belt are not the result of arc-continent collision, but are instead the result of tectonic activity similar to that observed today in many parts of the Mediterranean region.

MEDITERRANEAN-TYPE ANTLER OROGENY

Orogenesis within the Mediterranean alpine belt has produced mountain belts with a variety of structural styles. Two end-member styles have been described by Royden and Burchfiel (1989), who suggested that the differences in structural style may be systematically related to variations in local tectonic setting and thus may be useful in identifying mountain belts that have evolved in similar tectonic settings elsewhere in the world. Royden and Burchfiel (1989) proposed that continental subduction zones and orogenic belts can be loosely divided into segments that show no major back-arc extensional deformation adjacent to the belt (e.g., the western Alps, Pyrenees, and thrust belt of eastern Turkey) and segments that exhibit back-arc extension contemporaneously with thrusting (e.g., the Carpathian and Apennine thrust belts and the Hellenic trench). The segments that show no back-arc extension are found in areas where the rate of overall plate convergence equals or exceeds the rate of subduction and are commonly typified by extensive involvement of crystalline basement in thrusting, exposure of high-grade metamorphic rocks at the surface, high topographic elevation, and large amounts of erosion (tens of kilometres). The segments that exhibit back-arc extension are found in areas where the rate of subduction exceeds the rate of overall plate convergence and are commonly typified by thrust belts composed mainly of flysch-type sedimentary rocks, little to no involvement of crystalline basement in thrusting, a lack of high mountains, no belts of plutons or high-grade metamorphic rocks, relatively little erosion, and convexity toward their foreland.

We suggest that the Antler belt displays many of the geologic relations observed today in the Apennine, Carpathian, and Hellenic thrust-belt systems and that its evolution may be best explained by deformation within a tectonic setting similar to that of these young Mediterranean systems. In order to illustrate this point, we summarize below some of the aspects of these tectonic systems that are particularly relevant for understanding the middle Paleozoic Antler orogeny; we think that the Apennine system (Fig. 2) is most relevant.

The Carpathian, Apennine-Calabrian, and Hellenic systems have evolved within the broadly convergent setting between the European and African plates. Regardless of the way in which subduction began within these three belts, the Miocene to Holocene evolution of these systems does not appear to accommodate north-south convergence between Europe and Africa directly. Instead, the young evolution of these belts seems to be related primarily to the downgoing plate and to retreat of the trench toward the foreland (also referred to as slab rollback). As the subduction zones migrated toward their forelands, probably driven by the high density and negative buoyancy of the subducted lithosphere relative to the asthenosphere, a broad region of extension formed within the overriding plate. (For more detailed discussions of the young evolution of these thrust-belt and extensional systems, see the following: Carpathians—Royden, 1988a, 1988b; Royden and Burchfiel, 1989; Apennines—Scandone, 1979; Malinverno and Ryan, 1986; Royden et al., 1987; Kastens et al., 1988; Moretti and Royden, 1988; Hellenides—McKenzie, 1978a, 1978b.) Thus, in each system, deformation within the thrust belt was contemporaneous with extension in the overriding plate only 50 to 100 km distant from the zone of active thrusting. In the Carpathian and Hellenic regions, extension

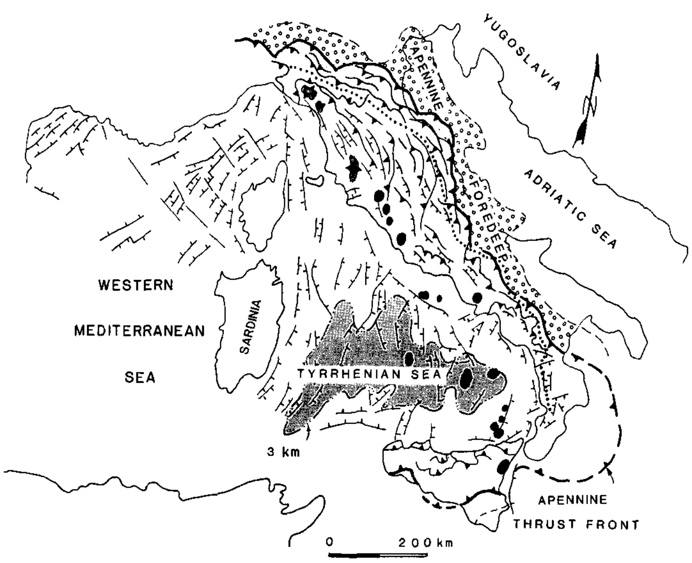

Figure 2. Generalized tectonic map of Apennine-Tyrrhenian Sea region of central Mediterranean area, showing major features of Neogene age. Barbed lines are east-vergent thrust faults of Apennines. Ticked lines are normal faults. Heavy dotted line is topographic divide of Apennines. Black areas are Pliocene to Holocene volcanoes. Gray is area below 3 km in Tyrrhenian Sea. Black is Tuscany metamorphic belt.

caused thinning of continental crust and formation of the Pannonian basin and Aegean Sea (Royden et al., 1988a, 1988b; McKenzie, 1978a, 1978b; Le Pichon and Angelier, 1981), whereas in the Apennine-Calabrian system, extension formed the thin continental and oceanic crust of the Tyrrhennian Sea (Fig. 2; Civetta et al., 1978; Scandone, 1979; Malinverno and Ryan, 1986; Kastens and Mascle, 1990; Kastens et al., 1988).

Thrusting within each of these Mediterranean belts is associated with arc volcanism in the overriding plate. Because the trench, thrusting, and extension have migrated toward the foreland through time, extension and subsidence of the volcanic arcs have occurred during or shortly after their formation. Thus, the extended area within the overriding plate is a region of subsidence and sedimentation that formed contemporaneously with thrusting in the external part of the thrust belt and contains subsided parts of the volcanic arc and slightly older parts of the thrust belt. For example, within the extended region west of the Apennines, low-grade metamorphic rocks that were formed near the base of the allochthon, such as in the Tuscany metamorphic belt (Fig. 2), were unroofed and unconformably overlain by sedimentary rocks even while thrusting continued farther east. Despite the abundance of volcanic arc material in these systems, volcanic detritus need not appear in the foredeep region. For example, the topographic divide of the Apennines separates the arc from the foredeep region (Fig. 2), and little eroded arc material has been deposited in the foredeep.

Subduction within the Carpathian and Apennine systems ceased when thick continental crust of the foreland entered the subduction zone. Within the Hellenic and Calabrian regions the subducted crust is thin continental or oceanic, and subduction is still active. This correlation strongly suggests that the density of the subducted lithosphere is key in driving subduction in these systems; although thick continental crust may be subducted a short distance, eventually subduction terminates when the subducted slab becomes sufficiently buoyant.

The Antler orogeny has many of the characteristics of these types of Mediterranean thrust belts, and a similar interpretation can be proposed for its evolution. Deformation followed by increased magmatic activity in the west-facing Klamath-Sierran arc initiated east-facing subduction in the oceanic or marginal sea behind the arc. A thrust belt developed as an accretionary prism to the east-facing subduction zone, and trench-retreat within the subduction zone (slab rollback) caused the thrust belt to migrate toward the continental margin. An enlarging extensional region formed to the west of the trench and thrust belt in the Havallah basin. Farther west, the west-facing Klamath-Sierran arc remained active, but following initiation of east-facing Antler subduction, it evolved independently of the Antler system. The thrust belt was emplaced onto the North American continental margin when the continental margin entered the subduction zone, and thrusting eventually ceased as the buoyancy of the subducted slab became sufficiently great to retard subduction. During emplacement of the allochthon, Havallah sedimentation began in the extending region to the west. Low-grade rocks formed in the Osgood Mountains were exposed by tectonic unroofing during extension and were unconformably overlain by post-tectonic Pennsylvanian sedimentary rocks. Arc volcanic rocks that may have been erupted in the hanging wall of the Antler subduction system were near or within a region of back-arc extension and were extended and subsided during or shortly after eruption. (This proposed setting is in many respects similar to that proposed by Burchfiel and Davis [1972, Fig. 3a], but no modern analogues for the Antler belt were recognized at that time.) The duration of Antler-related events from inception of subduction to final emplacement of the allochthon may have been about 25 m.y. Rate of emplacement of the allochthon onto the continental margin may have been about 1 cm/yr (Nilsen and Stewart, 1980). Using that rate suggests that about 250 km of lithosphere may have been subducted during Antler events. The amount of arc volcanism could have been reasonably small, yet the amount of extension could have been nearly as large as the amount of lithosphere subducted.

Other features commonly associated with thrust belts accompanied by coeval back-arc extension are limited lateral extent of the thrust belt, their filling of reentrants in continental margins, diachronous thrusting along the belt, and associated strike-slip faults. It may be significant that the Antler allochthon is present in the southern reentrant of the miogeocline. At the ends of the reentrant it contains complex structures that may be associated with strike-slip movement—for example, at its south end in central Nevada (Oldow, 1984) and at its north end in Idaho (Nilsen, 1977). The complex structural history that had been described by Oldow (1984) from the southern end of the belt is reminiscent of the structures that he has described from Sicily (Oldow, 1986). Depending upon the original geometry of the reentrant in the miogeocline, the structural style of the Antler belt in central Nevada may not have extended far beyond its present outcrops. It probably extended some distance to the southwest, because fragments of the belt are present in the Mojave Desert (Burchfiel and Davis, 1981) and perhaps farther south in Mexico (Stewart et al., 1990) where they were displaced by left-slip movement during late Paleozoic time (Stone and Stevens, 1988; Walker, 1988).

CONCLUSIONS

Thrusting within the tectonic setting proposed for the Antler orogeny does not require collision of an arc or continent. Therefore it is not necessary to postulate the presence of a collided arc west of the Antler belt, which must then have been rifted away or buried during postcollisional subsidence. In Mediterranean orogenic belts of Apennine type, a volcanic arc is present, but it is extensionally dismembered and subsides during its evolution. Such arcs do not "collide," and only the youngest part of the arc is passively accreted with the orogen. In such settings there appears to be minimal coupling across the subduction zone (Royden and Burchfiel, 1989).

If the above interpretation is correct, the entire Antler orogenic belt may be intact in the western United States, consisting only of a narrow thrust belt of oceanic and continental margin, slope and rise sedimentary rocks flanked by a coeval extensional basin immediately to the west and a foredeep basin to the east. Accretion of arc rocks in such a setting may not produce high mountains, and much of the accreted material may remain below sea level, receiving a cover of sedimentary rocks during emplacement.

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Reviewer's comment

Suggests considering the tectonics of the Antler "orogeny" . . . in terms of *rates* of relative plate motions, a viewpoint . . . commonly overlooked.

Tekla Harms
