Chert, a diagenetic and sedimentological indicator often misunderstood or forgotten, Mississippian from Alberta and world analogues

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Chert, a common component of many carbonate sequences, is a very good indicator of either the depositional environment or of the prevailing diagenetic conditions. A review of various types of cherts will focus on Lower Mississippian examples (Canada and Western Europe) with complements from worldwide analogues of other ages (California, Greece, Norway, Thailand, South Africa).

A) Synsedimentary cherts

Chert is a common component of most Lower Mississippian successions. It is often abundant and occurs in rhythmic alternation with dark lime mudstone often presenting slump features. Subsurface data confirms the extensive distribution of chert already seen in outcrops (Figs 1 and 2). Chert associated with clinoforms have been recognized in logs and in cuttings and have been interpreted to be responsible for some of the best seismic markers seen in Mississippian successions (Chatellier 1988). Recently Lilletveit et al (2002) have noted that opal transformation can be mapped as seismically hard reflectors.

Black cherts and rhythmic bedded cherts are most often associated with slopes and mass transport where cooler temperatures induce silica gel precipitation. They are frequently found with clinoforms, grain flow and slump deposits. Bedded cherts often correspond to non contorted part of slumps.

Cherts are common in Lower Mississippian sedimentary wedges that have been controlled by tectonics. Underlying and overlying strata exhibit facies changes also controlled by faults for example in the Exshaw (oolite in C section of Fig 1) or in the Pekisko (Martin 1967 in fig.4 parallel to the Banff wedge shown in the isopachs). This is also very well expressed in the Tournaisian series in Belgium where oolites banks and chert facies are structurally controlled.

Thick cherty units are found in association with grain flow deposits, fining upward or massive (e.g. in the Middle Banff of the Front Ranges). They are also found associated with biologically very rich, deep-water carbonate units that have been interpreted as mudmounds. Note that mudmounds have been recognized in the Tournaisian of Europe and North America but without any Stromatactis; the Waulsortian mudmounds are restricted to the Visean/Osage strata. Many evidences indicate that these mudmounds could be channel type infills that are killed by subsequent grain flow deposits (see Fig6). The mud mound nature may be due to the differential compaction taking place.

B) Late diagenetic chert

White to light gray cherts have been observed most often in association with late dolomite of hydrothermal origin (Fig.3). The occurrence of these cherts is commonly at the interface between highly or fully dolomitized rocks and partially dolomitized ones (Fig.5). The coexistence of white to gray cherts and of dolomite (mostly coarsely crystalline) are indicative of hydrothermal events in which a flush of hot fluids is associated with the precipitation of dolomite whereas the subsequent periods of cooling down are associated with chert precipitation.

The analysis of the data corresponding to the Middle, Lower and Basal Banff clearly indicates that white chert precipitation is related to the burial depth at the time of precipitation (Figs 8 and 9). Thus, because cherts do not precipitate under high temperature conditions, hydrothermal events will show a vertical change in diagenetic mineral assemblage. High burial depth will be essentially associated with saddle dolomite whereas at shallow burial depth, the lower temperatures of the hydrothermal fluids will be favorable sites for white to gray chert precipitation. The amount of chert decreases with depth indicating that the prevailing temperature increasing with depth is linked to a diminished precipitation of that mineral with depth.

At great depth hydrothermal mineral assemblages will be characterized by large amounts of sucrosic and saddle dolomite and no white chert. Whereas porous sucrosic dolomite are commonly poorly recovered and inadequately represented in cuttings, grey and white cherts are well preserved and can be a complementary and reliable indicator of hydrothermal activity.

The link between dolomitization and silicification is best expressed in the Parkland Field (British Columbia) and described in detail in Packard et al (2004).

C) Various analogues

1) The Miocene Monterey Formation (California)

In the cherty Monterey Formation, Eichhubl and Boles (1998) described a sequence of four vein generations, each representing multiple stages of fracture opening and cementation. These four vein generations correlate with the silica, dolomite, and organic matter alteration in the host rock sequence. Based on this correlation, the vein generations may thus be interpreted as the result of pore fluid expulsion during different stages of burial alteration of the sequence. In their study of the Monterey Formation Eichhubl and Behl (1998) have shown that unlike calcite and dolomite, quartz precipitation is favored by a drop in temperature.

The highest permeability estimates within the Monterey Formation are for chert breccias (MacKinnon, 1989), about one order of magnitude higher than for fractured but unbrecciated chert.

Shear along joint surfaces at high angle to bedding may lead to localized brecciation, preferentially where neighboring and overlapping joints interact (Dholakia and others, 1998). Although frequently confined to single beds, hydrocarbon infill of these breccias suggests that shear along joints may provide fracture connectivity for hydrocarbon migration.

2) Chert in chalk

Chert, also called flint is commonly found in chalk, however it is mostly restricted to allochtonous facies; facies that have been transported down slope. It can be present as laterally extensive beds or as nodules but it can be also be present as microscopic silica spheres that weakly bind the coccoliths together, a common feature in the North Sea.

Chalk is a rock composed exclusively of fossil remains, the chert are black and extremely rich in organic content (TOC), another evidence of the high biologic content of the original mud. Cherts, together with the commonly associated phosphates also indicate the potential source rock nature of the chalk.

The cherts are thus found in carbonate muds that have been transported to deeper and cooler environments. And similarly to the other occurrences of chert, there is association to an abundance of organisms.

3) Chert and transport downslope – A Greek example

A series of carbonate formations from Argolis (Greece) gives evidence of the links between chert precipitation and volcanism and between chert and mass transport down slope (Fig.10).

Within the upper part of the Asklepion tuff series, catastrophic grain flows have imprisoned an abundant cephalopod fauna of Bythinian age (e.g. Procladiscites jadosa, Ismidites marmarensis and Leiophyllites suessi). The catastrophic flow is expressed by perfectly formed plagioclases that crystallized within the cephalopods shells and by the common occurrence of associated patches of red and green chert and chloritized foraminifera.

The overlying Asklepion cherty limestone (about 1000 meters thick) is made of alternating decimetric mudstone and chert beds. In this carbonate slope facies characterized by transport and slump features there are numerous evidences of early silica migration from the lime mudstone to the chert layers; all of the radiolarians have been calcitized.

A very thick tectonic breccia (up to 600m) essentially made of chert fragments is present between the Asklepion nappe and the autochtonous Trapezona series. Its lower part corresponds to a wild flysch composed of numerous fining upward chert microbreccias in an overall coarsening upward sequence. It is capped by the massive Kandhia Breccia which is made up of very large chert clasts and in a limemudstone and chert matrix.

One of the most compelling similarities between each of the chert bearing formations described above is the transport of sediments downslope.

4) Hydrothermal chert in the Permian Ratburi Formation (Thailand)

Recently the diagenesis affecting the Nang-Nuan oil Field (Chumphon Basin, Thailand) has been reinterpreted as hydrothermal/deep burial in origin on the basis of fluid inclusions and isotopes (Heward et al, 2000). The main diagenetic assemblage comprises dolomite, grey chert, pyrite and H2S; all of these being the typical assemblage found in some dolomitized zones of the Mississippian successions.

5) Volcanism and cherts

Volcanism is often contributing to chert precipitation even if ashes, tuff or bentonites are not preserved or deposited. In these latter cases, dolomite rhombs are thought to be the indicator of volcanism (Fig.7). The diagram is based on observations and compositions from 17 Exshaw sections in relation to presence or absence of bentonite beds. Silica rich rock units are present because of the excess of silica in the system, organisms such as sponges are just thriving on these excesses of silica (volcanic activity).

The link between black cherts and high biological activity is nearly systematic from the Precambrian (van Kranendonk, 2001) to the Recent and is expressed by abundant fossil remains or by the preserved high organic content.

Abundant chert have been described associated with volcanism especially during the Eocene time (McGowran 1989, Lyons et al. 2000). Lilletveit et al (2002) have proposed a possible connection between deposition of volcanic tuffs and preservation of siliceous oozes.

6) Other interesting aspects of cherts

Note that the existence of chert inhibits quartz cement precipitation and thus is again contributing positively to the reservoir properties of a zone (Larese and Hall, 2003).

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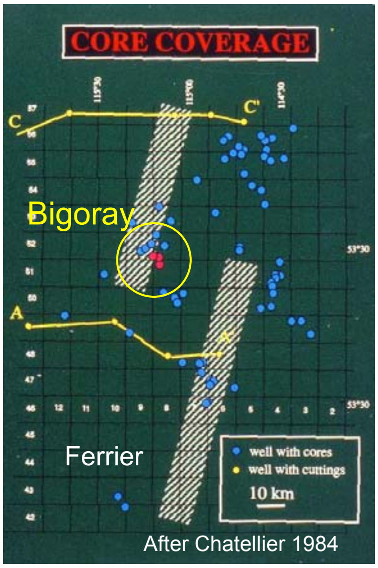


Fig.1 Core coverage

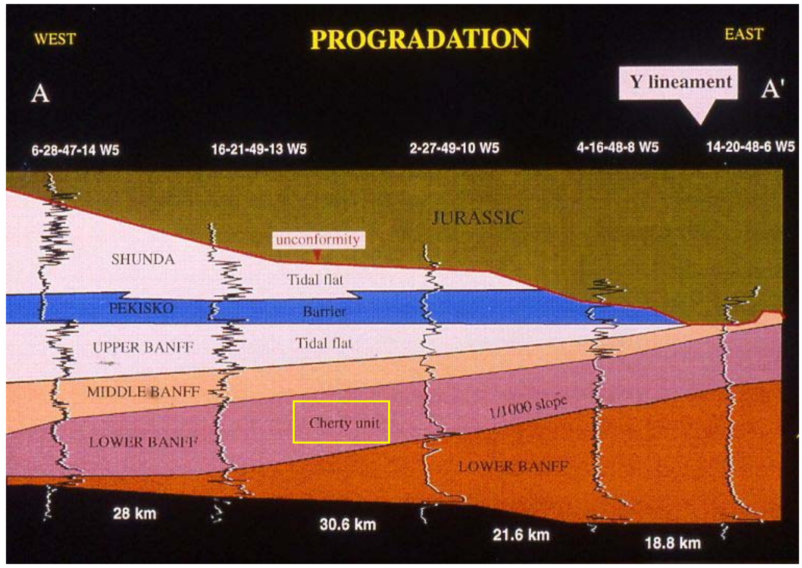


Fig.2 Structurally controlled cherty clinoform in Banff Formation

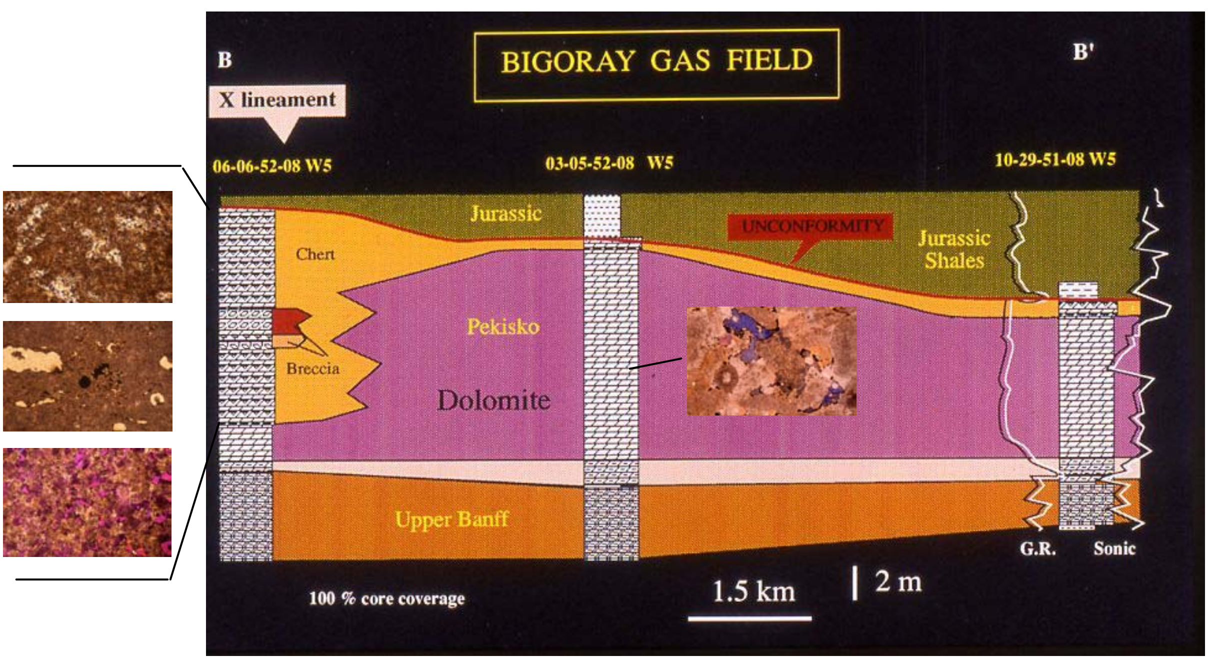


Fig.3 Structurally controlled diagenetic chert affecting the Pekisko Formation

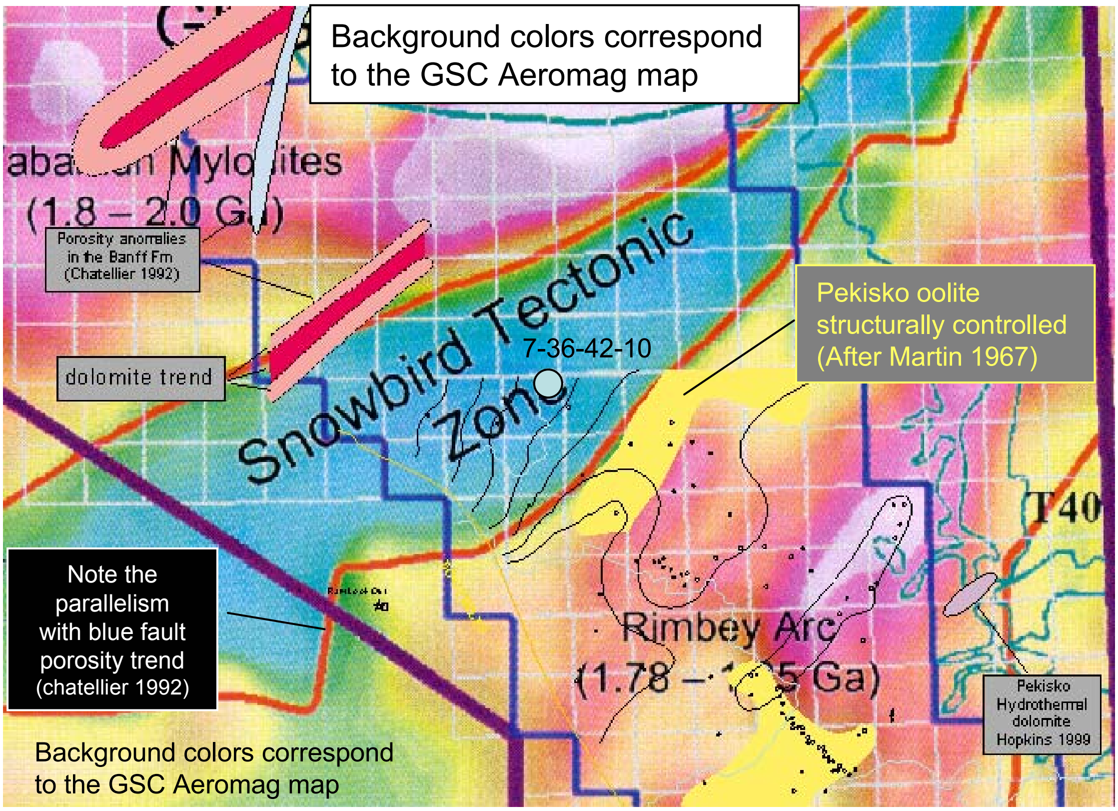


Fig 4 Structural control of sedimentation and diagenesis of Banff and Pekisko (Geographic setting)

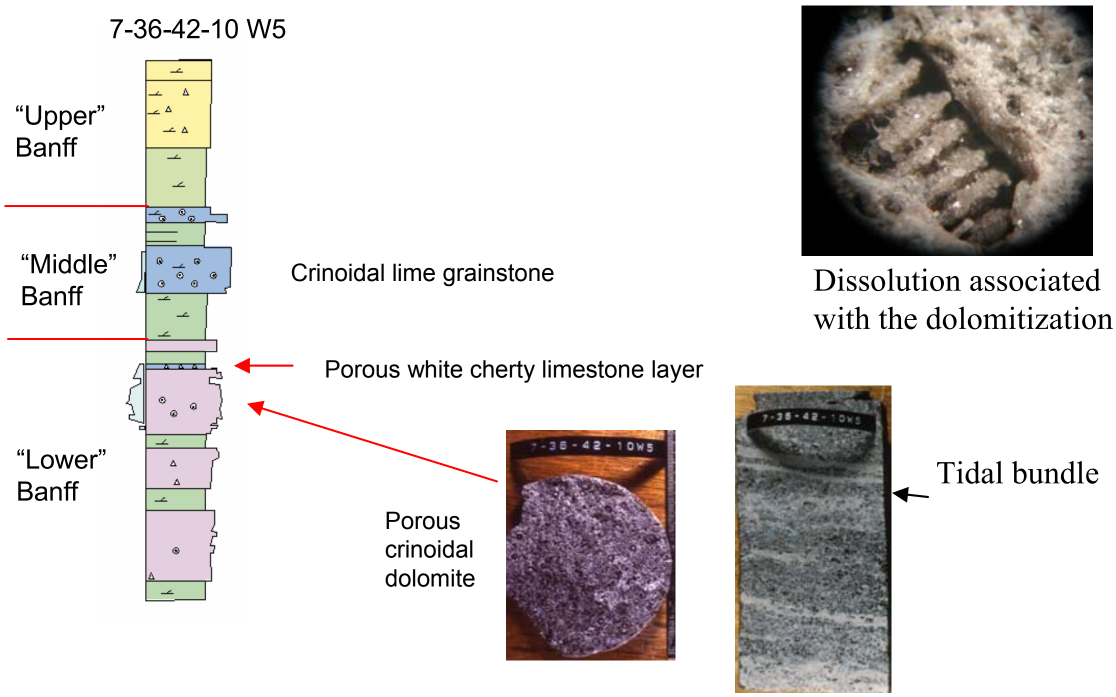


Fig 5 Association porous dolomite and porous white chert in cores from the Ferrier area

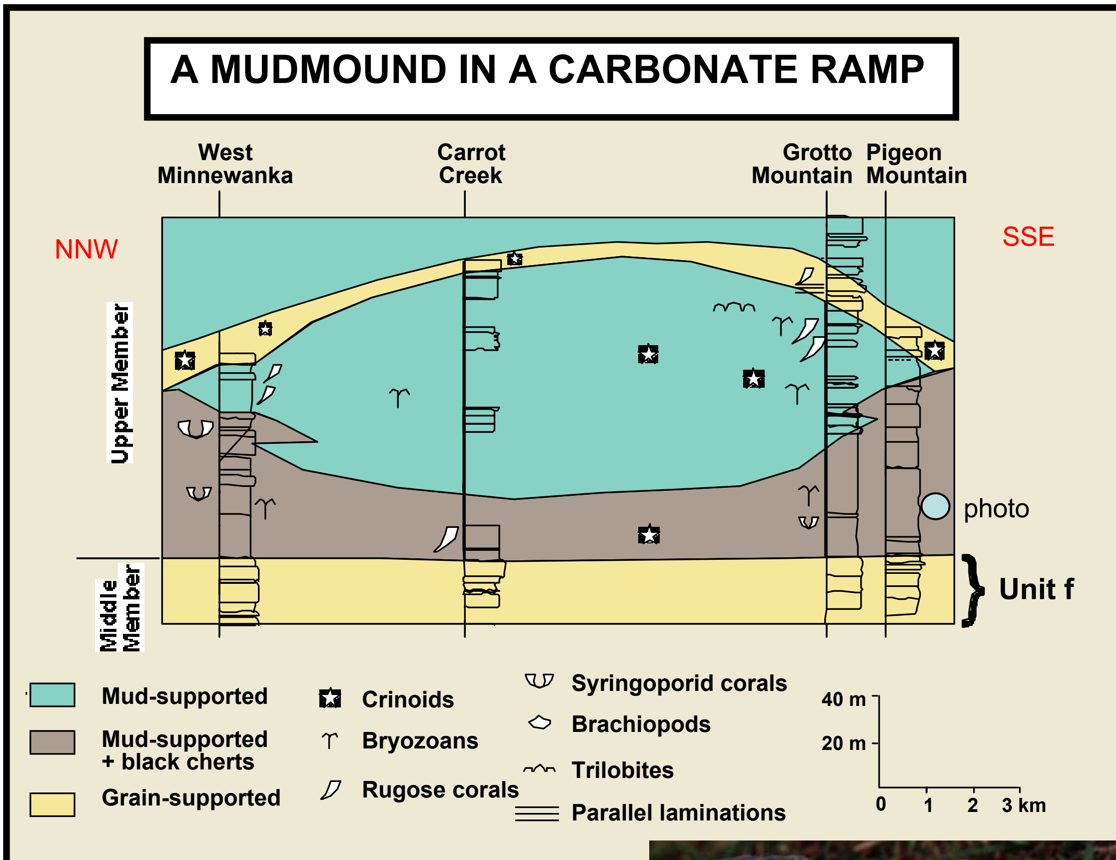


Fig 6 Grain flow chert and mudmounds in the Banff Formation

Expression of the fast precipitation of cherts associated with transport (Banff from Pigeon Mountain)

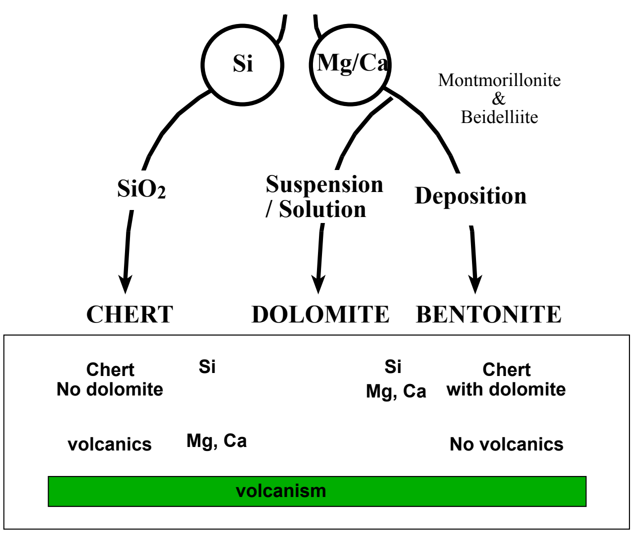
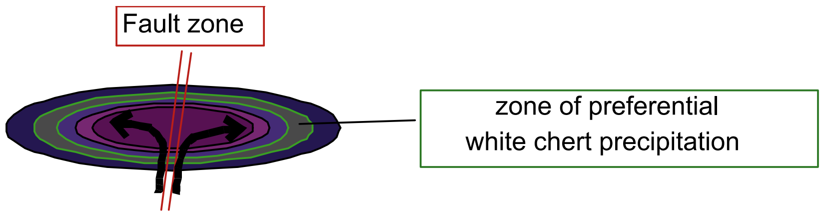
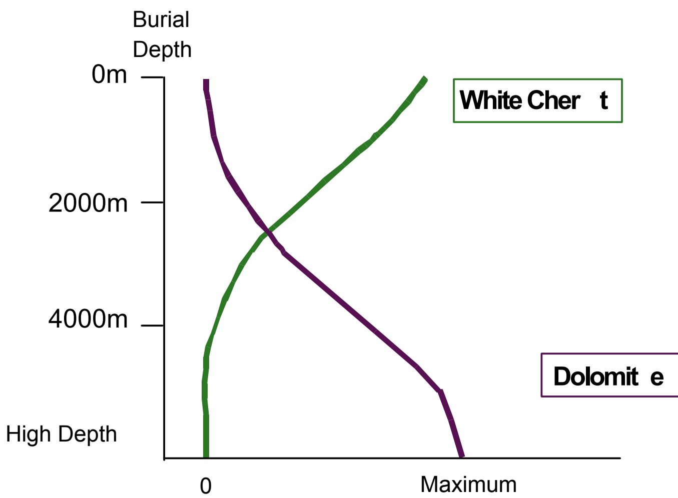


Fig 7 A very simplified view of the link between chert, dolomite and volcanism



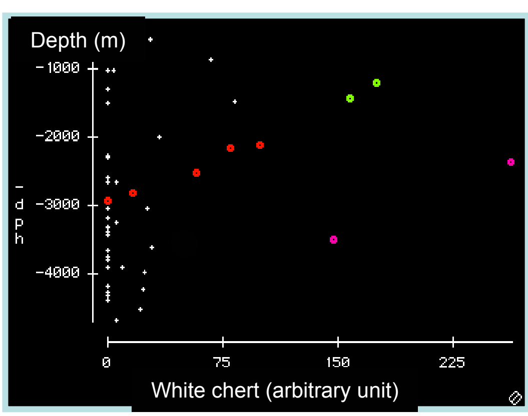
Hot hydrothermal pulse linked to dolomite precipitation
Late cooler period of hydrothermal pulse linked to white chert precipitation



Data from the plains

redrawn after J-Y Chatellier (1990)

Fig 8 Possible link between white chert and hydrothermal dolomite



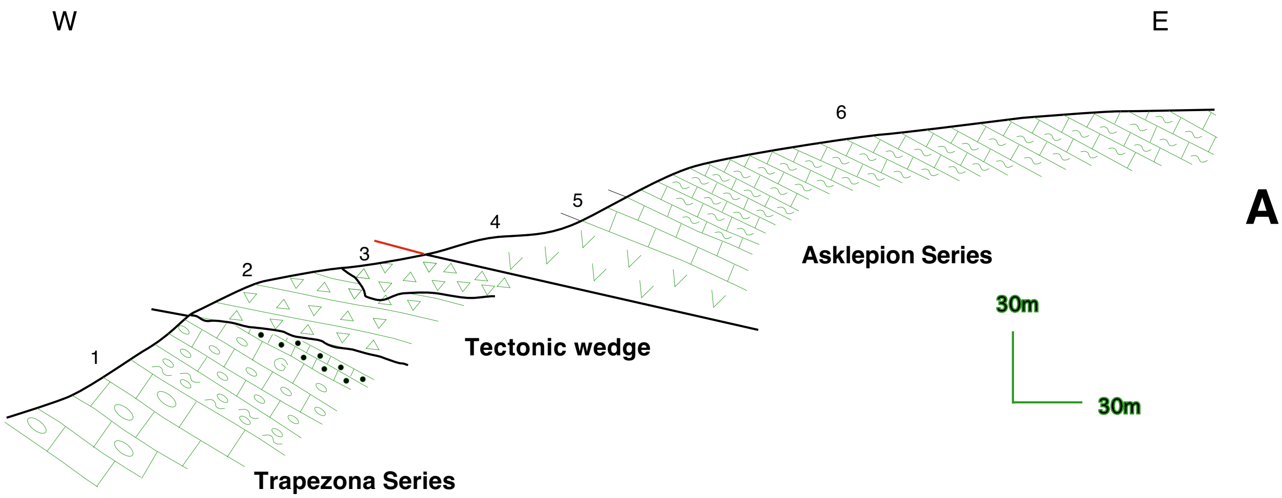
Grey cherts and sucrosic/saddle dolomite are both products of hydrothermal events

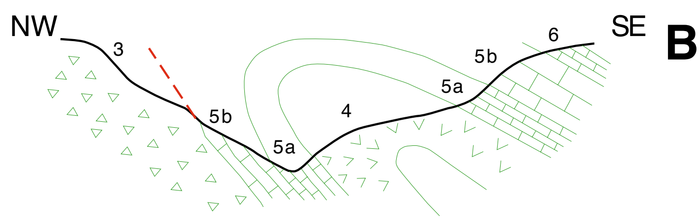
Dolomite during the flow of hot fluids
Grey chert during the cooling down of the intermittent flow

Different colors indicate different areas

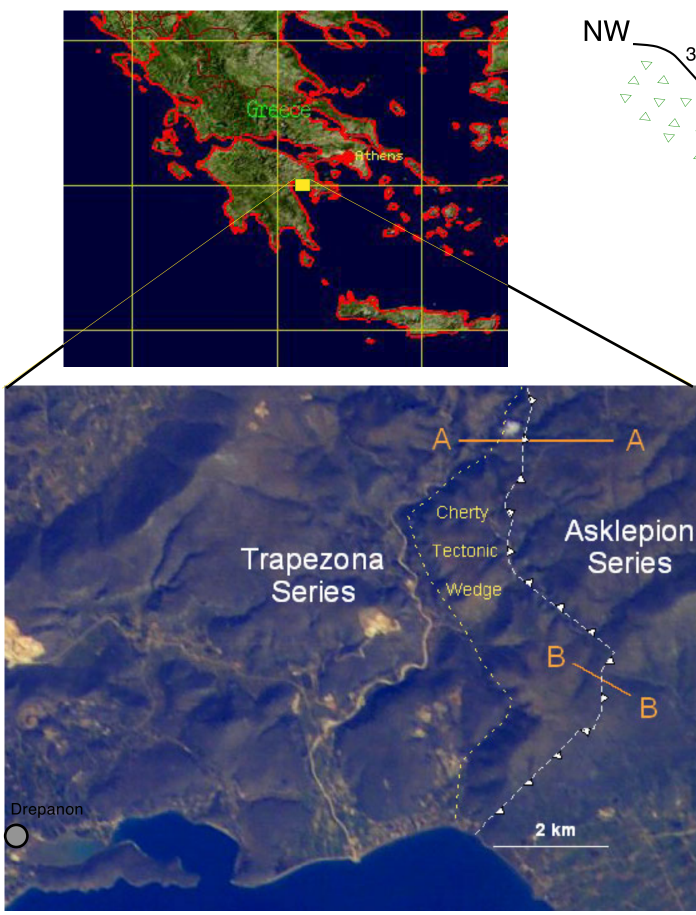
The red-green trend is shallower than other trends in the Foothills,
This may imply that some of the thrusting is post hydrothermal chert precipitation

Fig 9 Depth control on white chert abundance





modified after Chatellier 1980



Legend

6 Cherty Limestone Series (Trias-Lias)

5 Ammonitico Rosso (Trias)

4 Tuff Series (Trias)

3 Kandhia Chert breccia

2 Wild Flysch (chert clasts)

1 Trapezona Series (Lias)

Fig.10 The Cherty series of Argolida in their tectonic setting