

Overview

The topics of this manuscript is of major interest, since the Tertiary sedimentation allows to constrain the orogenic propagation in the Alpine foreland. The core of the manuscript consists of integration of new geochronological data (biostratigraphy, chemostratigraphy, magnetostratigraphy) with the existing database in a sequence stratigraphic framework, along with a synthesis of available well-log and seismic profiles. Besides this, the authors provide a reappraised structural framework based on existing maps, subsurface information from key seismic profiles, and field overview of some key areas. This reappraisal also benefits from some previously published field sections or even unpublished elements from the geol-alp.com website. These sedimentary and structural synthesis are correlated to propose a dynamic tectono-sedimentary and paleogeographic framework of the forward propagation of Alpine orogeny since Oligocene times.

This work is clearly worth of publication, provided it takes into consideration the comments listed below. The most reliable and solid input is the chronostratigraphical synthesis, and the important information brought by field sections and wells/profiles analysis. I have more reservations about the structural synthesis, which lacks kinematic data about brittle deformation (thrusts, faults), folds analysis, ductile deformation (Bornes) and transport directions, which also lacks 3D maps analysis, and which attempts anyway to conclude about stress evolution and chronology of thrusting. Thus, some conclusions appear overinterpreted, such as the complete allochthony of the northern Subalpine massifs, or the attribution of an Oligocene age to the earliest identified thrust (the paper is furthermore devoted to Miocene). From geodynamic point of view, the demonstration and time-space quantification of the forward propagation of the Alpine front since early-middle Miocene is convincing, although the geodynamic and structural inheritance and specificity of the Oligocene phase, along with older inherited structures (Hercynian trends), could have been better considered.

General comments

Organisation of the manuscript is correct but the "Geological setting" and the "overall structure.." § partly overlap concerning the description of main thrusts, their description in §2 could be simplified as both are describing fig. 1B; lines 115 and following partly duplicate § 4.3 (i.e. "the southern prolongation of this fault is contentious" found line 120 and line 348).

The structural descriptions of §4.3 are long and tedious, even the 4.3.6 "summary" trying to justify the options chosen in the cross-sections. Could be better organised and shortened.

Stratigraphy, sedimentology

This is of course the main input of the paper, thanks to field sections and synthesis of borehole data and seismic profiles. Synthetic sections provided in appendix are original and essential. The chronostatigraphic integration of different methods seems solid, and provides an essential framework to analyse the tectonosedimentary features.

Structures and deformation

Despite the structural study refers to "new field data", synthetic presentation of these new data is lacking (i.e. line 389 "210 stations.." without location location map nor data synthesis). Kinematics and structural chronology are tentatively deduced from maps analysis (fold and thrust trends), which is not suitable for proper identification of stress directions and discrimination of deformation phases. There is confusion between finite deformation (folds, thrusts) and "shortening phase", suggesting that paleostress can be inferred from the present structural trends, which is abusive. Thrusts and folds are oblique (eastern thrust in Chartreuse is western in Bauges) and sometimes curved. Such variations could be explained by structural inheritance beneath the foreland, with the possible influence of basement inherited structures oblique to Alpine stress, however this would require a specific microtectonic analysis is to determine paleostress, which obviously is not the main aim of this paper. Nevertheless, such analysis will now be facilitated by the improved chronostratigraphic framework provided by it.

Some more specific comments about FZ1:

The connection of thrust 1 both to the western Bauges and to the eastern Bauges implies that the Bauges and Bornes are regarded as an allochthonous nappe. This extreme opinion should be documented by

structural observations in the Eastern Bauges massif, which are lacking. Although deformed, the Jurassic cover near Ugine is not detached but only affected by distributed shear. The authors use the data of Gidon's website (i.e. fig. B1C = "unpublished" http://www.geol-alp.com/h_mt_blanc/_schemas/coupe_Aravis_mtBlanc_4.gif) but Gidon himself does not consider that the sedimentary cover of the Bornes massif is detached, although it looks sheared and deformed. The authors should provide additional structural data from their own to support the detachment interpretation, or give a better consideration to ductile deformation.

Thrust 1 shows a strong lateral increase in amplitude from S to N. It seems that accommodation is increasing northwards during the deposition of sequences S2 and S3, maybe the correlation between both should be underlined.

The onset of activity of FZ1 ("phase 1") is proposed as early Oligocene (5.1.1, fig. 16). I do not understand the argument for this? 1) eastward thickening of the Oligocene sequence in profiles 10B may be a flexural response related to more internal structures than FZ1, 2) Oligocene series are transported in the hangingwall of FZ1 (Bauges), 3) in the southern termination of FZ1 around Grenoble, there is absolutely no evidence for Oligocene activity, the thrust is overlying Aquitanian/Burdigalian, 4) early Oligocene corresponds to the activation of the Penninic thrust, further deformed by FZ1. This opinion must be better discussed and justified, and the "P1" bar in dashed line for Oligocene.

Other ZF:

The connexion from the Subalpine front to the Jura debatable:

The S-N continuity of thrust zones 2-3 remain a matter for debate even with the help of seismic profiles (i.e. FZ2 discussion p. 22)

The offset of FZ4 is much greater to the S (Royans) and tends to lower in front of N Vercors and Chartreuse (fig.9), this makes its northern continuity towards Jura questionable.

The extent of FZ5 to the N is not well constrained (line 522)

Moreover, the connexion of FZ2-FZ3 towards Jura + the interpretative roots of FZ2-FZ3 beneath Belledonne would imply that the Jura thrusts are rooted beneath N Belledonne, that is 150km further SE.. More generally, the boundaries of the structural domains appear to be defined and chosen "à priori" by map synthesis (fig. 1B, §2), so that the final identification of thrust activity is partly a circular argument.

Geodynamics

Oligocene is a very specific period from geodynamic point of view (west European rift system, Ligurian sea rifting) and the study area is located at the hinge between the Alpine orogen and the rift system. The inheritance of Oligocene structures and paleogeography could be better introduced. More specifically, I think that the "forebulge" interpretation put forward in section 5 and fig. 17 is, to me, somehow model-driven. The study area is large, and it would be worth to distinguish the flexural foreland situation in front of the Swiss molasse basin to the NE, from the Rhone valley rift to the SW. While a forebulge uplift seems reasonable in the former case (section A), the Royans Oligocene paleorelief is more probably related with the large-scale half-graben structure nicely illustrated in fig. 9D, whose Miocene reactivation of the eastern part localized FZ4-FZ5. I would not identify this structure as a forebulge.

Detail points

49-51 N-NW directed from Eocene to earliest Oligocene, driven by Adria-Europe convergence, then W directed motion driven by extrusion of the internal W Alps, leading to the radially propagating arc.

59 "...Vercors and Chartreuse.."

60 "...NNW-SSE trending Miocene thrusts.."

63 "...date from the late Burdigalian.."

65 "Further south, .."

73 "...well-logs and field sections."

77 "as a response to the western propagation of the Alpine orogen during the Miocene."

81 also quote De Graciansky, P.C. de, Roberts D.G., Tricart P. (2011), The Western Alps, from rift to passive margin to orogenic belt, an integrated overview. *Developments in Earth Surface Processes*, 14, Elsevier, 398p., ISBN 9780444537249

103 "...the westward progressive migration..?"

105 fluvial deposits?

108 "...folds and thrusts affecting the sedimentary cover, trending NNW-SSE.." some folds are ~NS? "last WNW-ESE shortening phase" is overinterpreted, paleostress cannot be assumed to be perpendicular to present fold trends, nor can be determined along balanced cross sections whose orientation was chosen à priori.

112 please locate (from N to S of what?)

120 a more recent ref. about the Moucherotte thrust is still missing (Donzeau, Gamond & Mugnier, CRAS 1993 vol 317 p. 1675)

146 split the sentence after Gidon, 1964

150 ".the Jura fold belt is progressively widening northwards."

151 "..anticlines that develop in the hangingwall of blind thrust.."

160 also quote Lickorish et al. (2002) GSA Bulletin 114, 9, p. 1089

168 "..from 35 well-log and outcrop sections.."

171 ~~scale~~ resolution?

331 "..in the footwall of the Penninic thrust.."

347 "..thrust over.."

349 not sure that "a saddle of the folds" is correct..

357 "new field observation" should require structural measurements, only landscape views are presented.

358 "suggest" incorrect

361 does it mean that the Sassenage anticline is partly older than Miocene? to be demonstrated, fig. 6B does not show anything

361 "On each side.."

362 how can you determine fold trends so precisely without structural data? not visible in fig. 7a

364 a better argument than the map trace would be a view of 3D geological map

365 this is already proposed by Gidon 1995, fig. 1, must be quoted

367 is this left-lateral displacement necessary considering the dip of the Neron-Moucherotte thrust and the topography? 3D view would be useful

389 what means "..at 210 stations"? where are the location/data? should be removed if it is not presented. I do not find this detailed map of the Moucherotte thrust. Would require at least 3D map view for discussion

391 "..thrust above the Miocene on top of.."

395 this thrust at the base of Comboire cliff is not the main Moucherotte thrust because the footwall rocks are Berriasian, whereas the footwall of the main thrust should be younger (Valanginian, see Gidon, geol-alp website, page Comboire, and quote it). The argument is difficult to understand from your text.

401 ".. overlain by.."

402 fig. 6C? "..the lower Cretaceous strata are steeply dipping eastwards"

403 text description very difficult to follow

405 "..in the footwall of the thrust.."

414 "extend"

417 "..but dips locally to the west, strongly suggests that.."

419 in contradiction with the trace of the "Corenc tectonic window"..

420 no, "External Belledonne" is basement, here this is cover

424-425 the displacement along the "Corenc-Jalla" thrust seems much lower compared to Neron

431 I do not understand this sentence, please clarify

435 there seem to be confusion between a "thrust" and a shear zone, what is the thickness of the folded section?

438 Bellahsen et al do not figurate a complete detachment across the Bauges massif

446 once again structural data should be synthetised in stereograms, not as individual numeric values in the text.

450 may be this can be interpreted as southward decrease in thrust displacement as for FZ1?

453 veers? sentence unclear

455 this is the classical view from the Grenoble 1/50000 sheet and Gidon papers, see also Dumont & SPIA, 2020, Geol Soc London Spec Publ 486 doi:10.1144/SP486-2019-92

470 "Its interpretation suggests that.." Complicated discussion, it appears that the S-N continuity of the individual thrust zones is interpretative and debatable, even with the help of seismic profiles.

485 not found the OU thrust in fig. 9B, inherited from Deville 2021? check consistency: Outherans/Outeran, SA anticline not on fig.10, FZ1 text is 1 on fig.10.

489 why "west-dipping GF"? seems to be E-dipping everywhere

496 I do not understand, the potential connection is not visible on the profiles of fig.10

504 "..by steep west-dipping.."

509 "..offset is estimated to.."

508-511 major thrust .. (FZ3) / the main fault (3) : be consistent in the text description

516 offset along 4 + 4a on line 82... looks greater than 650m (~1,5km?)

526-530 this presentation is a bit oversimplified, both thrust traces and fold trends vary between NS and NE-SW, and even NW-SE following the interpretations about the FZ continuity in Jura.

534 further north what? BZN1 quite impossible to locate on fig.1, too small. What is the importance of this triple occurrence of Js? ("duplicated three times" means that Js occurs 6 times?)
535 "an uplifted compartment" where?
543 quote fig. 18 or remove?
545 "Klippe" is just a result of erosion, it does not have any implication in terms of displacement or location of "roots"
550 .. or simply that Subalpine and Jura thrusts cannot be individually connected?
552 also quote Lickorish et al., 2006; Deville 2021.
555 veer?
566-572 this discussion lacks kinematic data, in the absence of which it is not possible to decipher the relative chronology between thrusts and transfer/strike-slip faults. Similarly, the orientation of compression cannot be constrained from maps only. Do the southern Jura thrusts imply a NE-SW compression?
580 "In the footwall of FZ1.."
587 "..in the footwall.."
588 ".. the deposition of Oligo-Aquitainian sediments"
591 "..both Oligocene and early Miocene sediments.."
683 "are proposed using the.."
718 ".. while the regressive systems tract.."
723 (and elsewhere) "Therefore, the sequences S6 and S7..."
724 "..is either synchronous or younger than the deposition of sequences .."
751 and §5.1.1 there is no direct evidence of the activity of FZ1 as soon as early Oligocene, the Oligocene sedimentary sequence is compatible with a flexural foreland but, as said line 763, the eastern boundary of this basin is unknown. Moreover, Oligocene is transported in the Bauges massif, suggesting that the orogenic front was located further east. This option should be presented as an hypothesis and the phase 1 (P1) on fig. 16 put in dashed line.
792 what means « concordant on the folded Urgonian », is Miocene folded with Urgonian ?
797 the wavelength of flexural subsidence is several hundred km , consistent with the lithospheric thickness, this process can hardly be involved for a depocenter in the footwall of an individual thrust.
803 hypothesis
805 "..the thrusts that are interpreted to root beneath the Belledonne massif.."
806 uncorrect sentence (and the S6 sealing...)
807 "end of phase 2" is time, "in the subalpine massifs" is location, unclear
809 "..are overthrust by the Jura units.."
810 ~~posterior~~ younger than..
812 tectonically-controlled..
813 "..even perhaps coeval with the deposition of S7 continental sediments"
829 "..suggests that thrust activity stopped after the deposition of S5. There, the uppermost marine.."
834 the link between the arguments presented since line 828 and "activation of out-of-sequence thrusts in an internal position" is unclear. Moreover, such structures should produce subsidence in their footwall, not uplift; and isostatic rebound is mentioned line 833. So please clarify your interpretation of a "tectonic event" involving "lithospheric processes", it is now clear that the recent uplift of the W Alps is not directly linked with plates convergence, and is probably not "tectonic".
855 backthrusts are compatible with thrusting, they do not need another tectonic phase?
875 the onset of phase 1 as soon as early Oligocene is not well constrained, must be given as hypothetical.
875-880 there is an overlap between phase 1 and 2? (17,8Ma+/-?? - 18,05+/-0,25Ma), better use Early Burdigalian line 875?
881 the "Belledonne basal thrust fault" is actually unknown, no outcrop, no seismic, no borehole. Must be presented as an interpretation.
899 "..recorded after the deposition of S5"
901-903 I do not understand which tectonic structure could be involved to explain this uplift by tectonic processes in Bas Dauphiné? there is no evidence of shortening, and the situation is different from the N Alpine foreland.

Figures

Figures are generally of good quality, and contain a lot of information, but will be hard to read on a paper copy.

Figs 4 & 5 dense but clear, this is the core of the data

Figure 6: A and B are not very clear because of backlight, a 3d view of the geological map draped over DEM would perhaps give a better overview. Picture H can be processed to get better colours

Fig. 7: Why are the cross-sections named both with numbers (1-6) and letters (B-G)? confusing. I do not understand the trace of the east part of FZ1 outcropping both W of Corenc and E of Grenoble, not compatible with cross sections 1 & 2.

Fig. 9: are the interpretation based on Deville 2021 or were the lines completely reinterpreted? must be clarified

Fig. 11: I remain reluctant considering the FZ1 detachment over Belledonne in section A, and I totally disagree with its trace above Belledonne in section D: the normal fault offset is Jurassic as demonstrated in the 80s (La Mure fault) as the Liassic series have very different thickness on both sides (Lemoine et al., 1986). Must be changed.

Fig. 13: sections identified using both n° and letters (3 = A, 4 = B etc.), keep only n°?

Fig. 15 please refer to the location of transects on a map

Fig. 17: the activation of FZ1 to the east is not consistent with the occurrence of Oligocene deposition in the futuer Bauges massif, that is in the hangingwall of the thrust. The activation of the Belledonne thrust as soon as ~20Ma is in contradiction with the exhumation ages which are younger.

Fig. 18: (A) = cross-section B; (B) = cross-section C. confusing! "restoration"