SUPPLEMENT TO

NEOGENE AND PLEISTOCENE GEODYNAMIC : THE PALEOSEISMIC EVOLUTION OF ARMORICA

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COMPLEMENTS (Millières)

Annotated pictures of the field data

(author of the pictures: B. Van Vliet-Lanoe)

Millières stratigraphical reappraisal

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The "Gelasian" base of the Millières Formation was reached by coring in the basin (Figs 12-14 in this supplement) Its stratigraphic attribution to the Gelasian (Baize 1998; Dugué et al. 2012) resulted from the occurrence, in the lower cored unit, of the cold-water foraminifera *Elphidium* or *Elphidiella hannai* (Margerel in Baize 1998). This unit was considered by these authors to be eroding the "St Vigor Formation", considered as early Quaternary (Dugué et al. 2012) but dated by ESR at 3.7 Ma (Van Vliet-Lanoë et al. 2002; Fig.11).

Elphidiella hannai is not a clear marker for a Gelasian age. It evolved during the Oligocene in Alaska (Lagoe et al. 1989), today inhabiting the inner shelf of the NE Pacific margin, from southern California to Alaska, and being found at shallow depths in the Scoresby Sund Fjord (East Greenland) (Resig 1964; Madsen and Knudsen 1994) or south of 53°N in the southern North Sea (Resig 1964). Marine diatom biostratigraphy has suggested that the first opening of the Bering Strait took place just after 7.4–7.3 Ma (Marincovich and Gladenkov 1999). Pacific faunas were thus able to reach the central Atlantic before the second major glacial event, dated at ~ 6.7 Ma (Herbert et al. 2013), such as at Pénestin (Fig.6) (Van Vliet-Lanoë et al. 2009). The occurrence of ice-rafted blocks in the lower Millières Formation supports this hypothesis (Figs. 12 -14).

In addition, from a palynological point of view, the lower Millères Formation has been attributed to the Gelasian (Clet in Baize 1998) due to the presence of boreal pollen. Boreal genera, such as *Alnus, Betula, Salix, Ulmus, Abies, Pinus*, and *Pterocarya*, have existed since the Oligocene (Turgaï flora) (Meyen 1987). During the Tortonian–Messinian, the climate was mild-temperate and humid (indicated by *Ulmus, Castanea, Ilex, Pinus,* and *Ericaceae*) in Western Europe (Gardère and Pais 2007; Utescher et al. 2007; Quan et al. 2014), but interrupted by major glaciations (11.8, 9.0, 6.7, and 5.4 Ma) (Table 1). This "interglacial" vegetation

This “interglacial” vegetation allowed the development of podzolic soils containing orstein (due to the high water table) to evolve in more arid locations to the south. This was the case for the Lessay Basin, which was imprinted by sand wedges (permafrost) on tidal sands, and were capped by an orstein containing boreal pollen. It is further truncated by a late conglomerate, which was initially attributed to the middle Quaternary (Coutard et al. 1991).

(references in the main bibliography)aphy)

Table A

Stages	EUSTATIC CYCLES	WESTERN & EASTERN CHANNEL	COTENTIN RECORD	Tectonism & sismicity/Climate NORMANDY	Tectonism & sismicity / Climate BRITANNY	BRITTANY RECORD
	Upper		**Raised beaches**	Load casts (Genêt)	**Drag folds (Quiberon)**	**Raised beaches, Lower terrace**
135 -275 ka	**Ionian (MIS 9a - MIS 7a)**	E. Channel breaching	**Raised beaches**	-	Load casts, clay diapirsm	**Raised beaches, Lower terrace**
275-310 ka			**Climate cooling, enhanced erosion, isostatic uplift, river incision**			
310-500 ka	**Ionian (MIS 15 - MIS 9 c)**	E. Channel breaching Hurd Deep	Raised beaches	-	Load casts, clay diapirsm, water escape	**Raised beaches :** Trez Rouz, Gwendrez, Pen Hat, Penestin **Middle Terrace II** (Oust, Vilaine)
1000 -700 ka	**Upper Calabrian /** MTP		**Climate cooling , buckling, enhanced erosion, isostatic uplift, river incision**			
1.Ma 1.8 Ma	**Lower Calabrian** -------------------------		Load casting Marchésieux complex St Nicolas de Pierrepont Petit-Port platform slightly weathered	Subsidence/ relaxation ? Transtensive folding /(Riedel) on Eure FZ (HT) Load casts	Seismicity, clay diapirism Transtensive folding Large loadcasts *Ice rafting*	Menez Dregan platform slightly weathered 1.2 ±0.16 Ma. Réguigny 1.43 ± 0.18 Ma **High terrace** (Oust, Vilaine)
1.8- 2.58 Ma	**Gelasien-Waalien**	Transtensive folding /Riedel (Confluent, Hague Deep ?)	Upper Fm Lande de Millières ss (stratified clay) Bohon Crags Bosq Clay La Londe clay	Subsidence/ relaxation	Load casts, faults with offset , clay diapirism, water escape tilting,	St Jean-la Poterie *Nassa* clays Landerneau Clays 2.45 ± 0.35 Frelonnière (Rennes) 2.43 ± 0.35 Landerneau 2.3 ± 0.3 Reguigny
3.3 Ma			Up. Saint Vigor sands, 3.2 ± 0.4 Ma	**Major Climate cooling, Erosion and isostatic uplift, titling**		Fm Radenac 3.05 ± 0.5 & 3.3 ± 0.5 Ma **Very high terrace** (Oust & Vilaine, 3.2 Ma
3.6 Ma 5.3 Ma	**Piacenzian** --------------------------- **Zanclean**	E. Channel opening	Upper Lozères sands Lessay sands Periers Middle Fm Lande de Millières ss	Subsidence/ relaxation Drag fold Water escape Recumbent fold	Subsidence/ relaxation, Water escape; Synsedimetary limited co-seismic activity, Transtensive faulting (Le Rhys, Musillac)	Fm Radenac 3.5 ± 0.7 & 3.8 ± 0.5 Ma Fm Landerneau base (4.2 Ma) Fm SR d'Apigné 5.35 ± 0.8 Ma Penestin Pliocene LS tidal channel Musillac
6.0- 5.3 Ma	**LATE MESSINIAN**	Manche River	Marchésieux sandstone Lower Fm Lande de Millières (gravel) Summit of the Lower Saint Vigor Fm	**TRANSPRESSION (Buckling), Erosion and isostatic uplift ?Climate cooling , erosive polished coastal platform, orstein**		
6.0 Ma 7.2 Ma	**Lower Messinian**		Lower Saint Vigor sands Lower Lozère sands (Rouen Middle Terrace I)	Transtension Water escapes, faulting *Ice rafting,*	Transtension Water escapes, faulting, Flower structures *Ice rafting, stone frost jacking*	Fm Reguigny 6.5 ± 1.0 Ma Pénestin LSt (beach) 6.7±0,7 Ma Pors Kubu St Malo de Phily Middle terrace 1
7.2-11.6 Ma	**Tortonian**		Valmont tidalites Low Lower Fm Lande de Millières *(Elphidae)*	Transtension		Fm Bolan 7.0 ±1.0 & 8.7 ± 1.5 Ma
		River incision	Major regression / upper PS 6-2-. Surface, Middle Terrace (Oust, Vilaine)			

Annotated pictures of the field data

Figure 1 : Le Rhys-en-Douarnenez *(SASZ) paleocliff, possibly tortonnian in age on a shall platform, covered by faulted and consolidated Pliocene sands(A); B &C) periglacial slope deposits and eroded paleocliff (caves) cemented by Fe-Mn orstein*

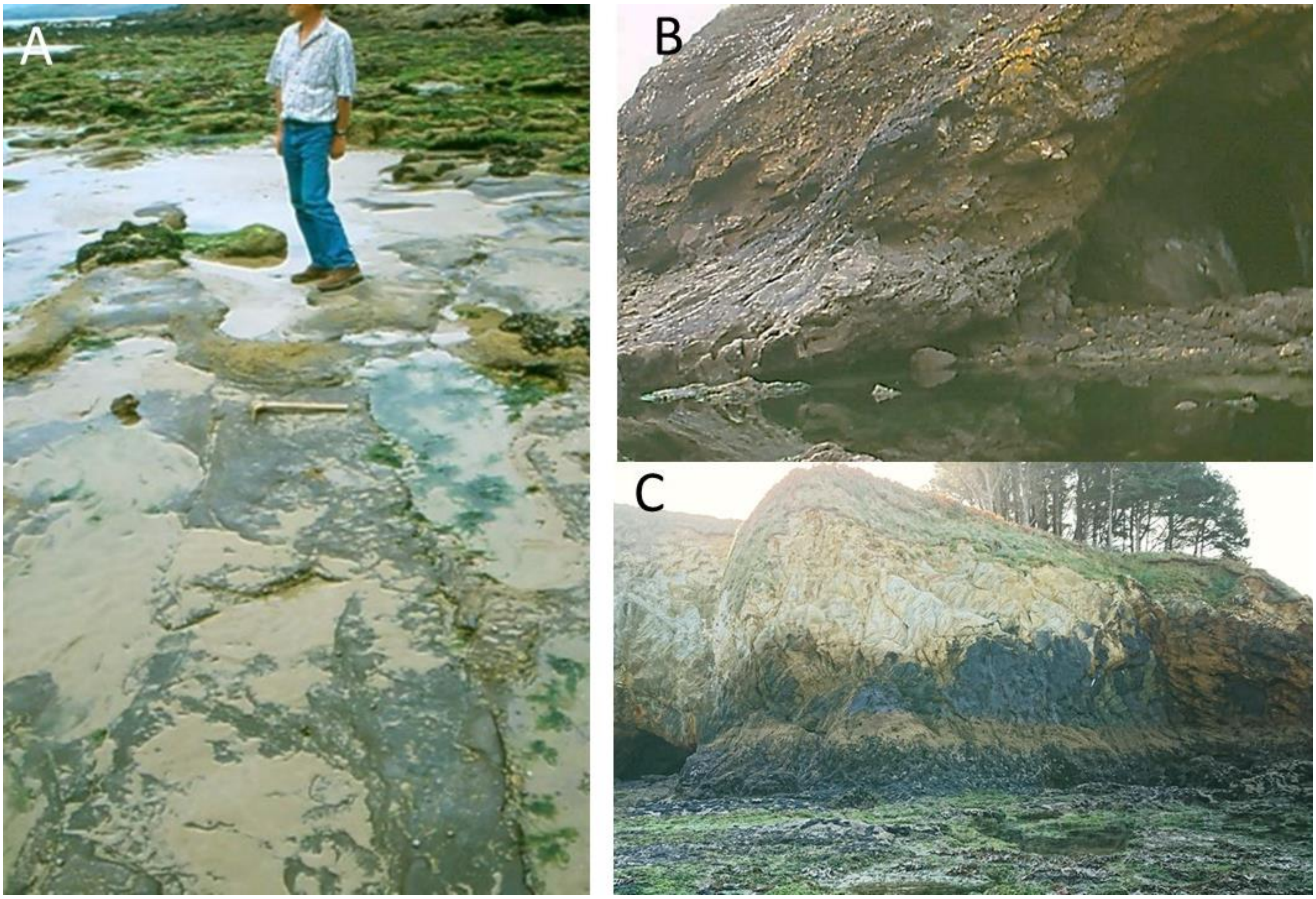

Figure 2: Pors Kubu ***(Crozon Peninsula, Western Brittany)*** *1) lower cobble beach including very few ice rafted blocks in a shall sand matrix, and resting on a polished platform, 2) Upper cobble beach, initially openwork, rich in ice rafted flat lying blocks , cemented by goethite. 3) Storm ridge formed by the mixing of slope deposits and beach cobble, cemented by goethite orsteins; 4) slope deposits derived of shales burying a polished cliff, infiltrated by a thick red clay illuviation. This system is not faulted but truncated by a middle quaternary beach (MIS 9 or 11).*

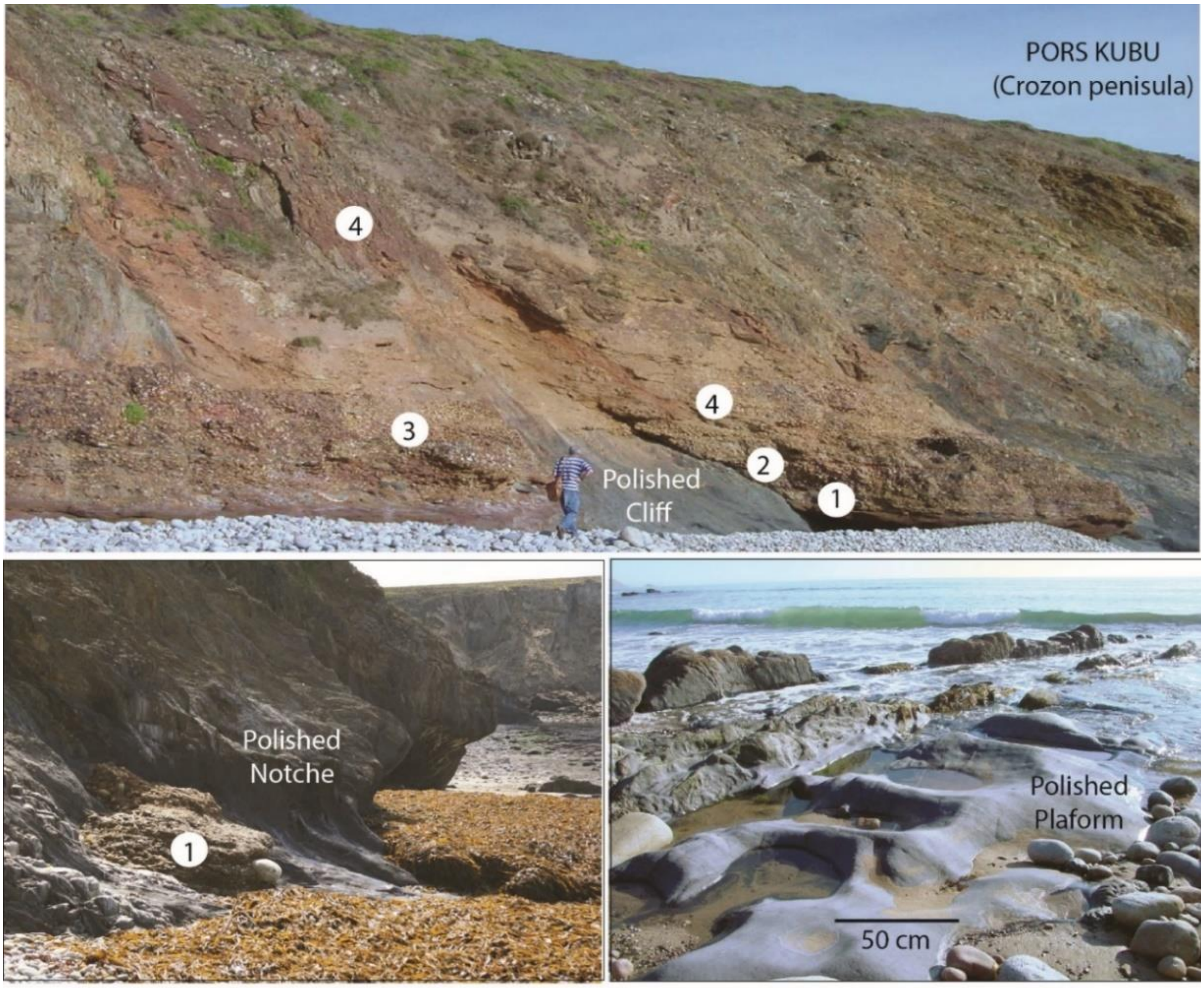

Figure 3 : REGUIGNY (Lafarge quarries) *: Gelasian and early quaternary at the top of the sequence with load casting probably close to 1.1 Ma from ESR dating.*

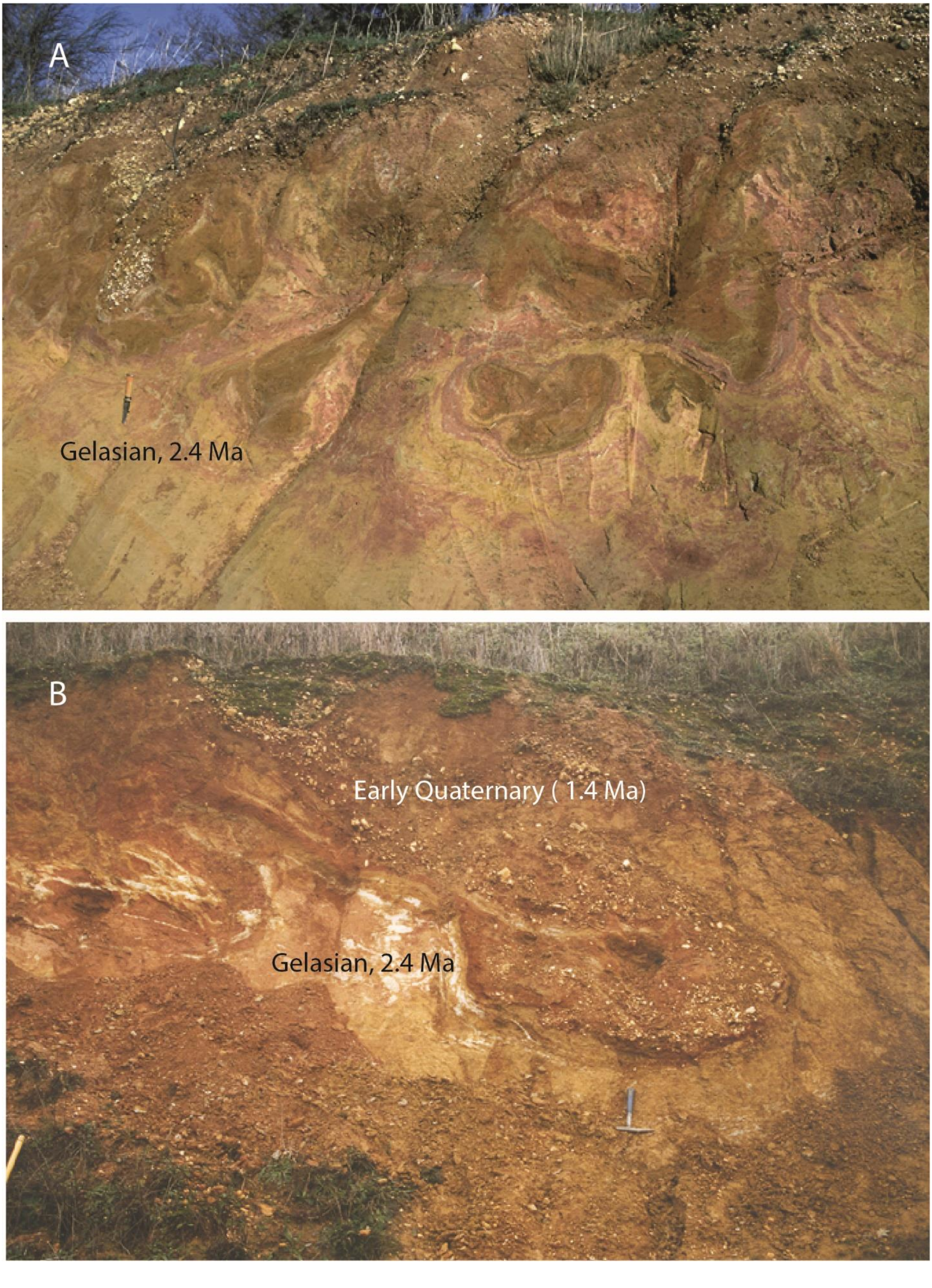

Figure 4: Saint Jouan de l'Isle (NASZ) *: polyphased water escapes on faulted late Messinian (A—C) or very early Zanclean gravel (D)*

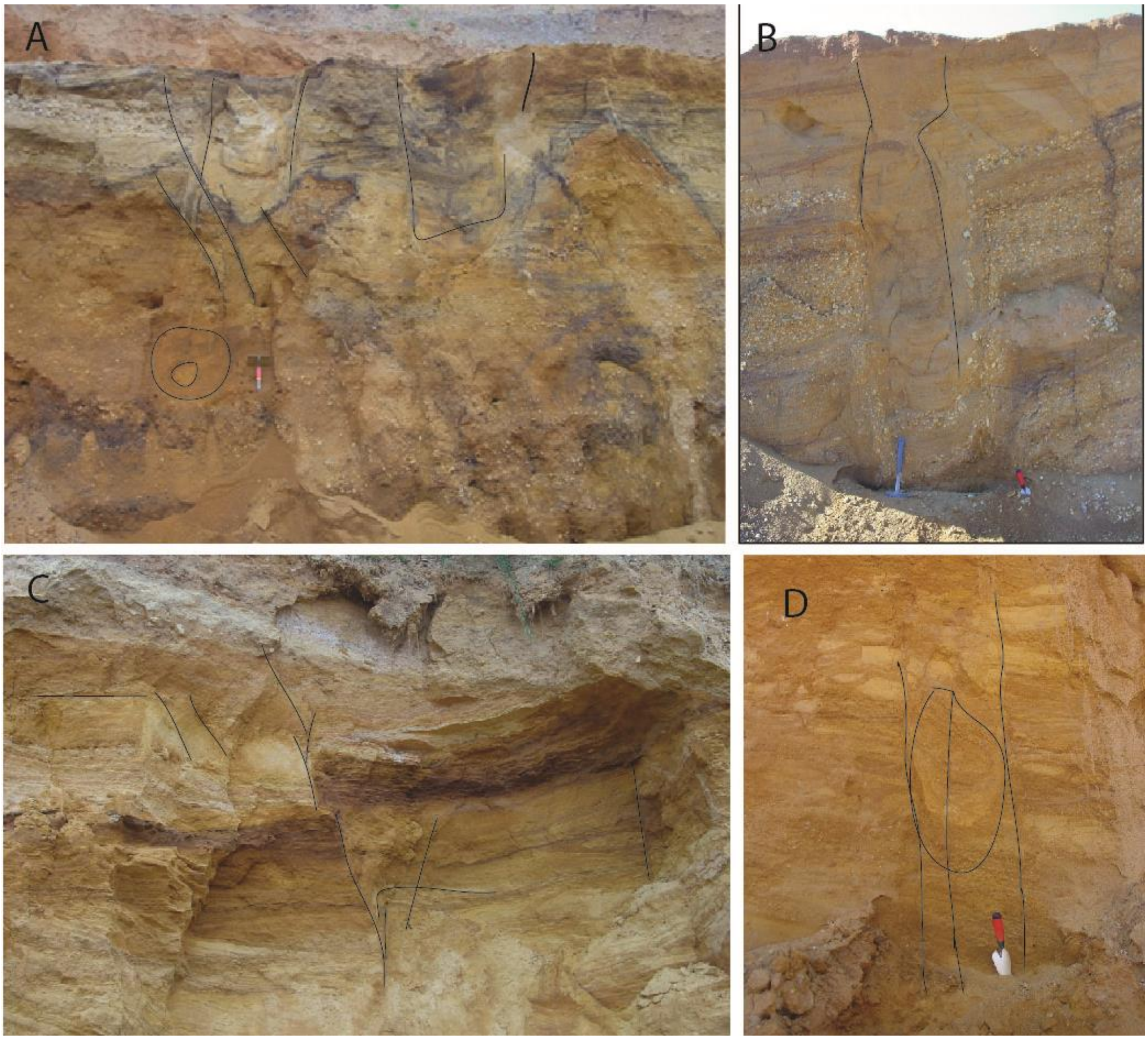

Figure 5 : Saint Malo de Phily *(Vilaine River valley, highest terrace) Transtensive wedges in an upper Piacenzian terrace.*

Figure 6 : Pénestin North (Vilaine River estuary) *Stratigraphy*

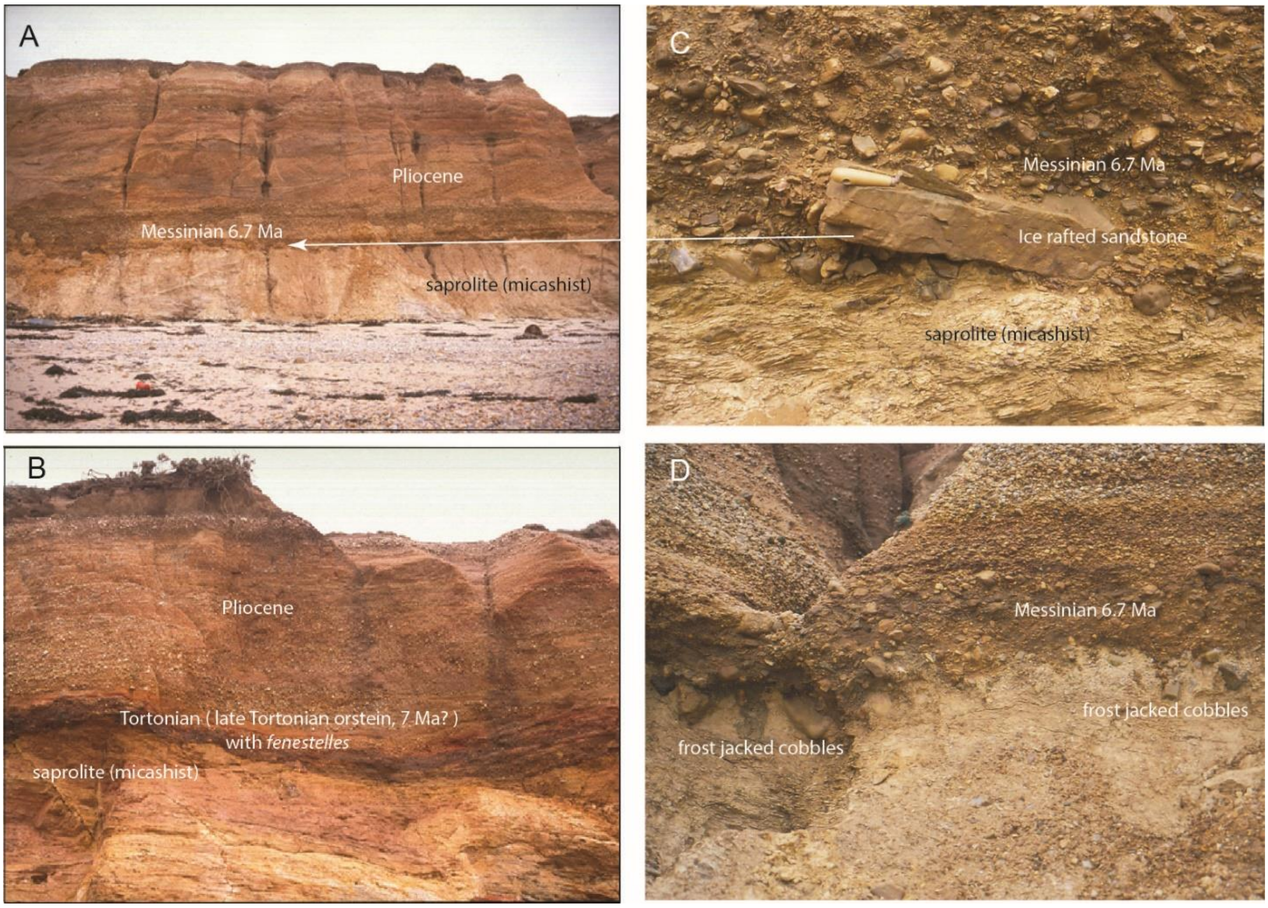

Figure 7: *Trez-Rouz (Elorn fault): co-seismic Shale and peat diapirsm (Msk : 4,5-5), probably around 400 ka . Dragged by periglacial solifluction.*

Figure 8 *: Herquemoulin (1995): cliff notch parallel with the lithology (metamorphic shales). Probably MIS 9a . Covered by MIS 8 heads (scale: large block in the sun: 30 cm). Abrasion platform in foot cliff position.*

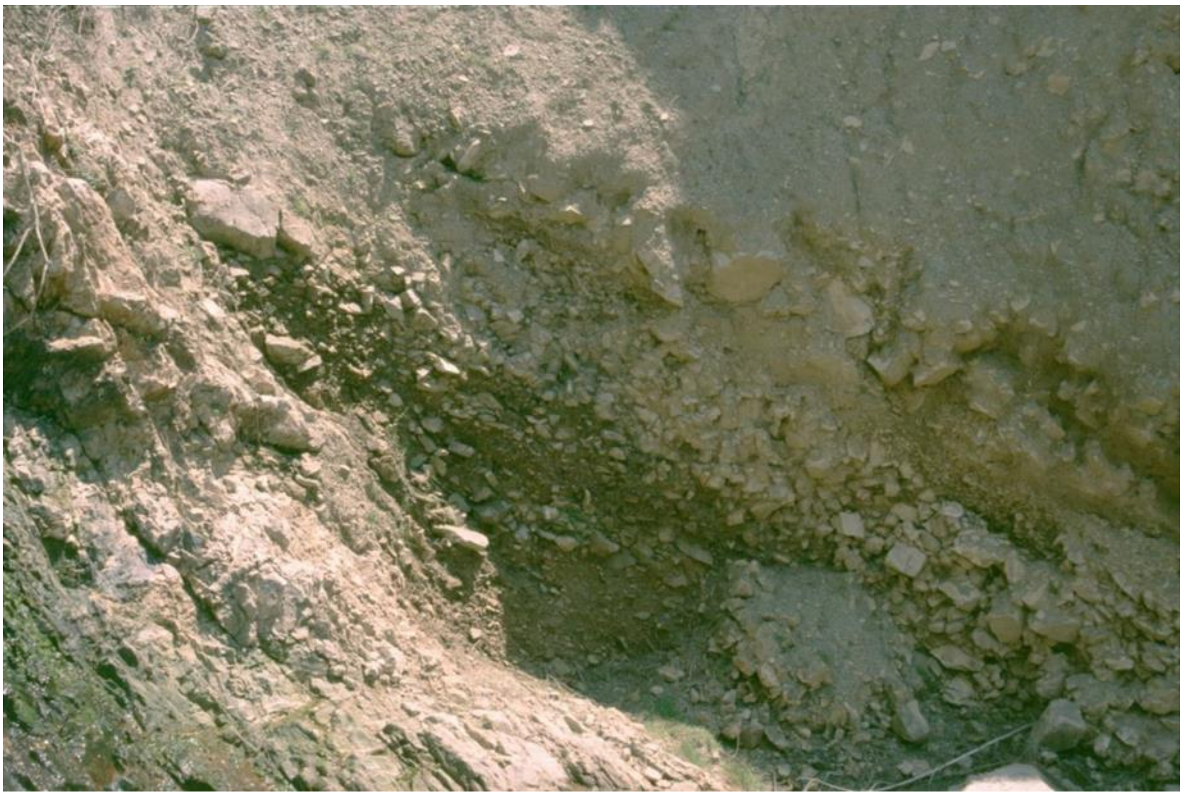

Figure 9 Avranches : *giant loadcast in truncated paleogene saprolite*

Figure 10: Landes de Lessay: *sand wedge rupturing a boreal (palynology) upper Tortonian red-yellow podzol with orstein (arrow) in a conglomerate (Late Messinian), truncating a Tortonian- Messinian Tidal sand . Star: location of the palynological analysis (Bh soil horizon). Two sand wedge generation, one before, and one after the orstein formation.*

Figure 11: Esquay (St Vigor) *water escapes. A) contact with the Lower unit : gravelly sands, probable late Miocene in age, B & C Upper unit dated by ESR at 3.2 ± 0.4 Ma*

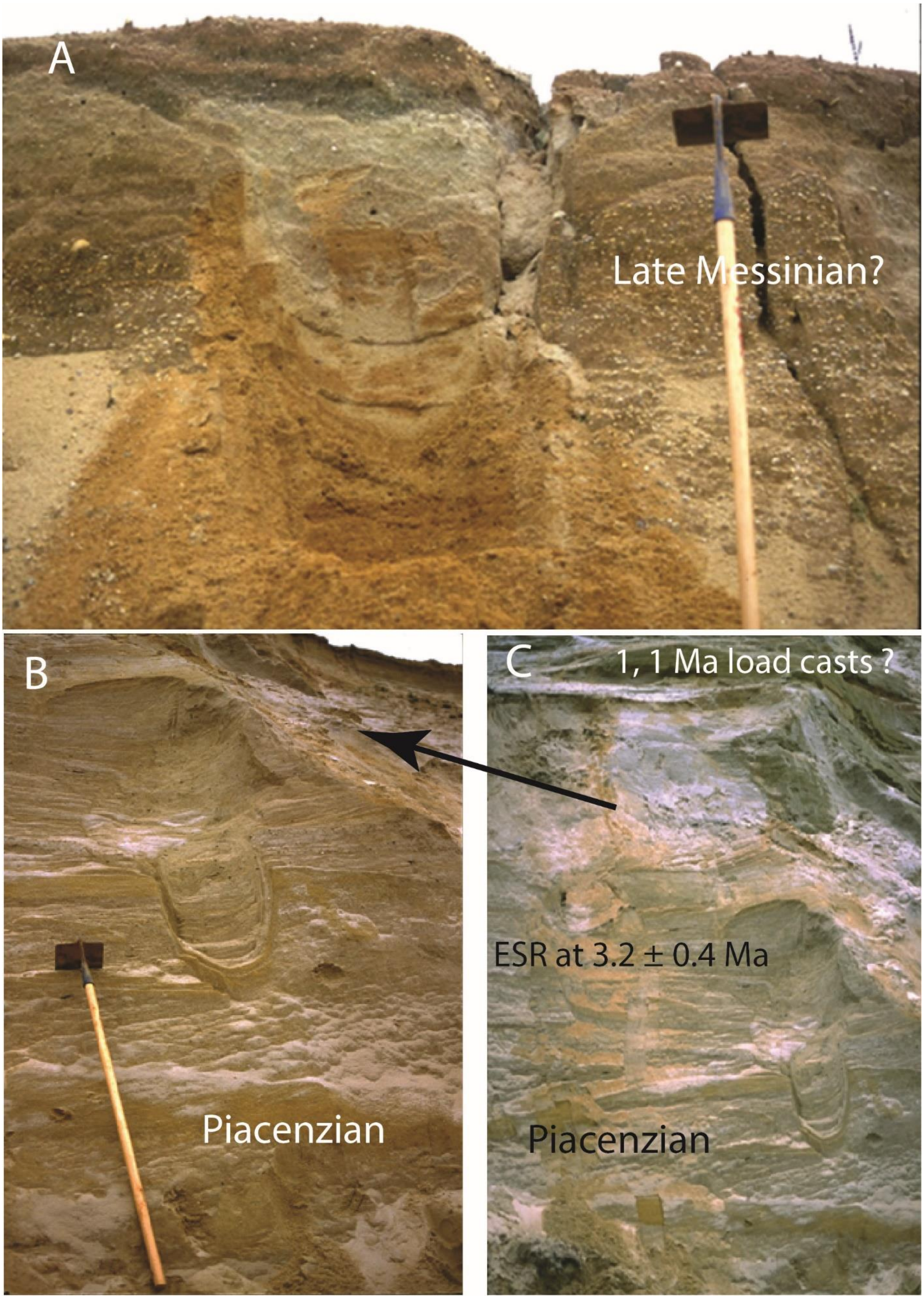

***Figure 12 Millières quarry** (pictures 1995) **:** Upper Millères formation with re-interpreted ages (see main text)*

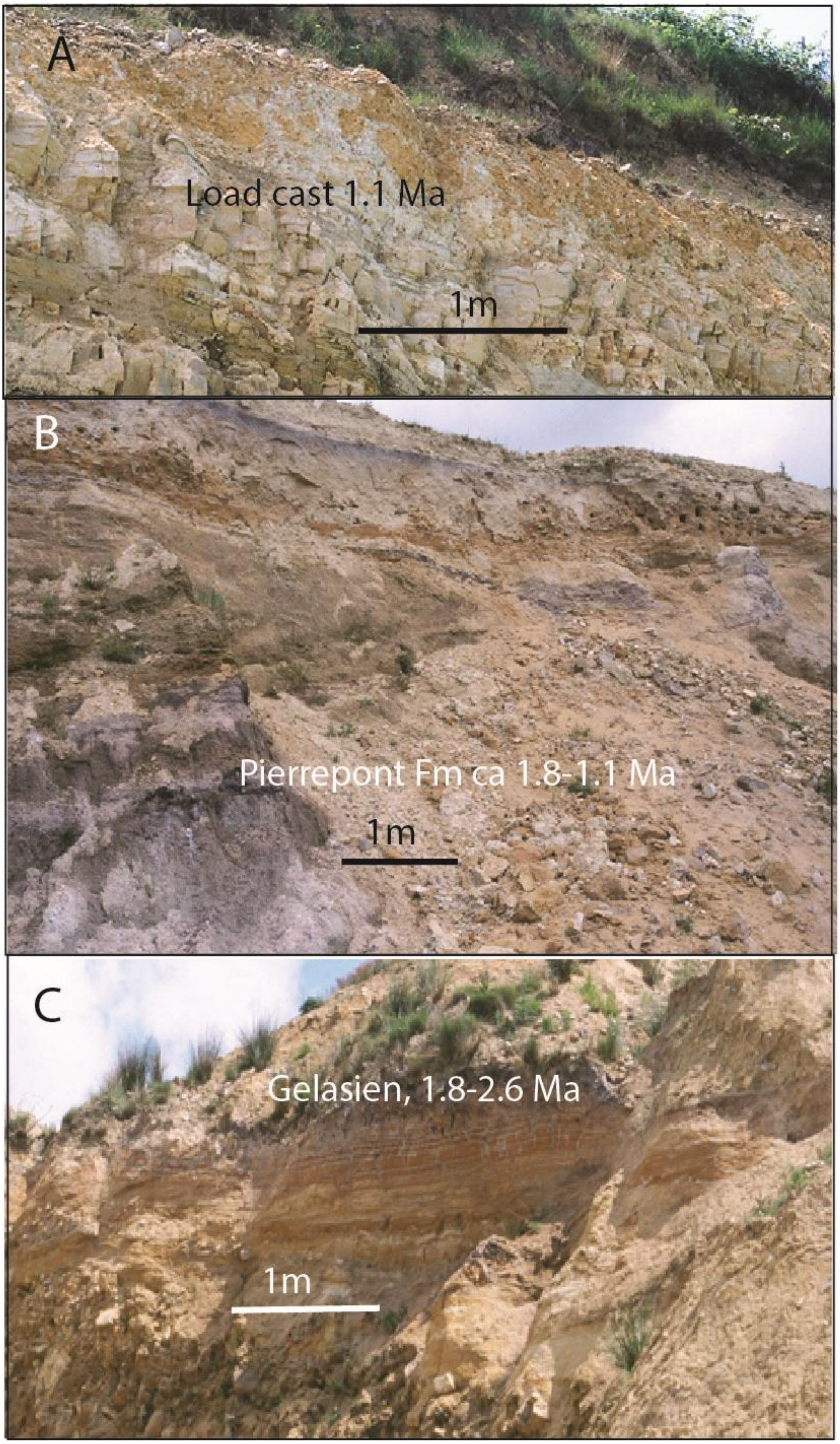

***Figure 13: Millières quarry** (1995): Middle (MM) and lower Millères formations (LM) . A) Pliocene with co-seismic recubent fold; coarse grained upper Lower Millières Fm (Messinian) C), including frost shattered and rafted erratic blocs (C) low Lower Millières Fm (Tortonian tidalites).*

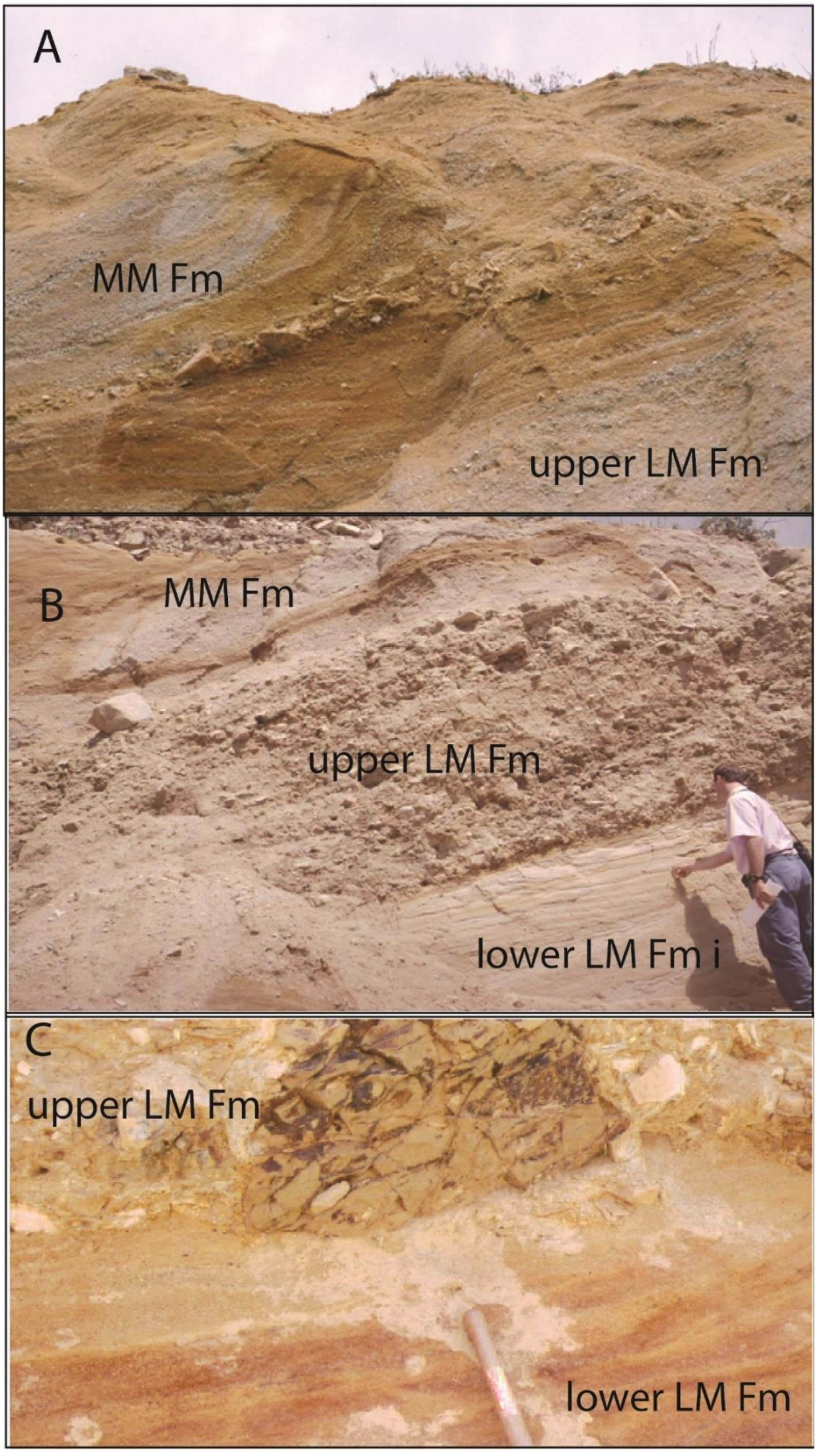

***Figure 14 : Millières quarry** (1995)**: faulting.** Middle (MM) and lower Millères formation (LM)n . A) coarse grained upper Lower Millières Fm (B), including transtentional faulting (B & C), B) hemigraben with drag fold.*

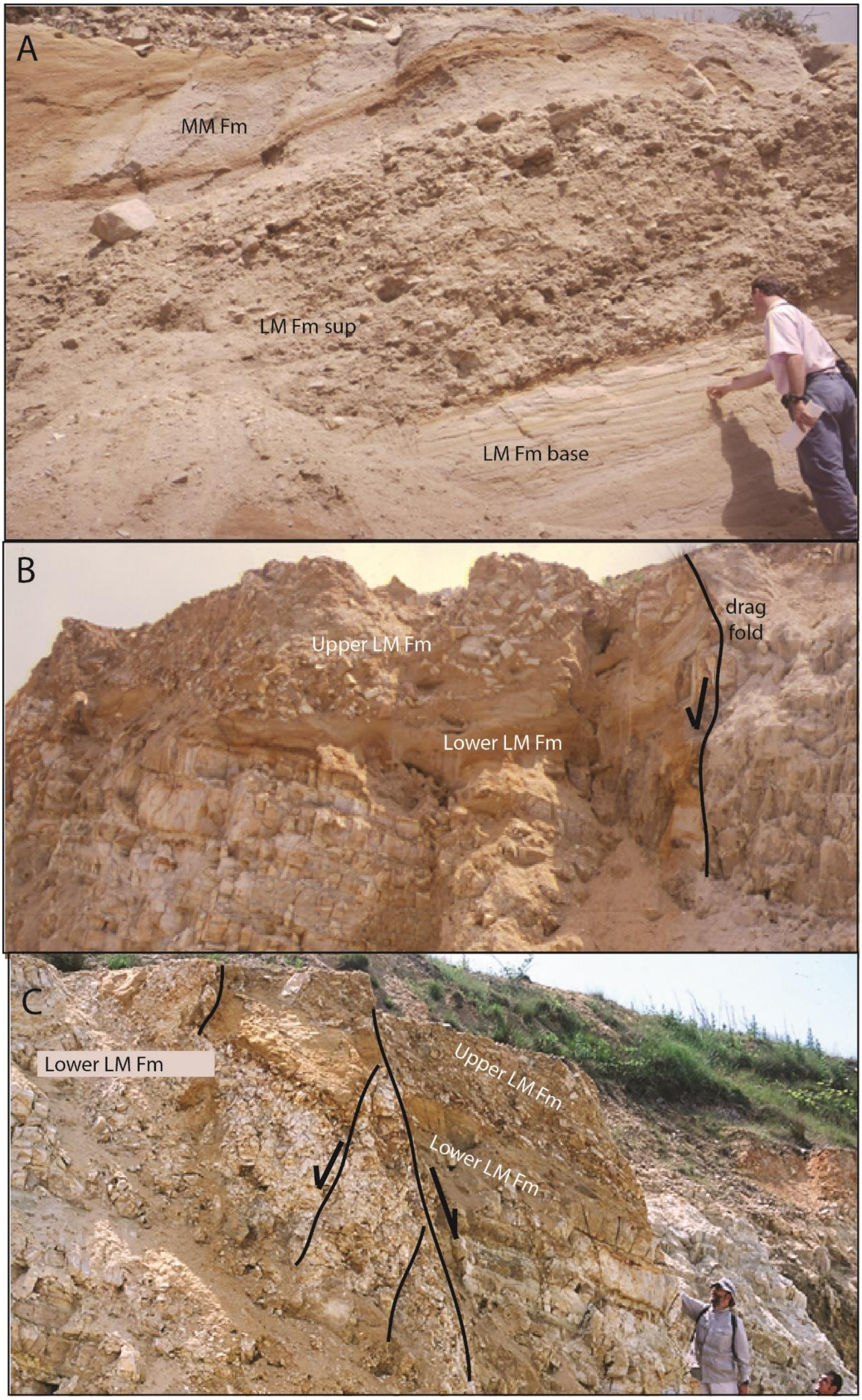

***Figure 15**: A-B : **Lalonde quarry**: karstic faulting, C: **Valmont quarry** karstic and /or thermokarstic.*

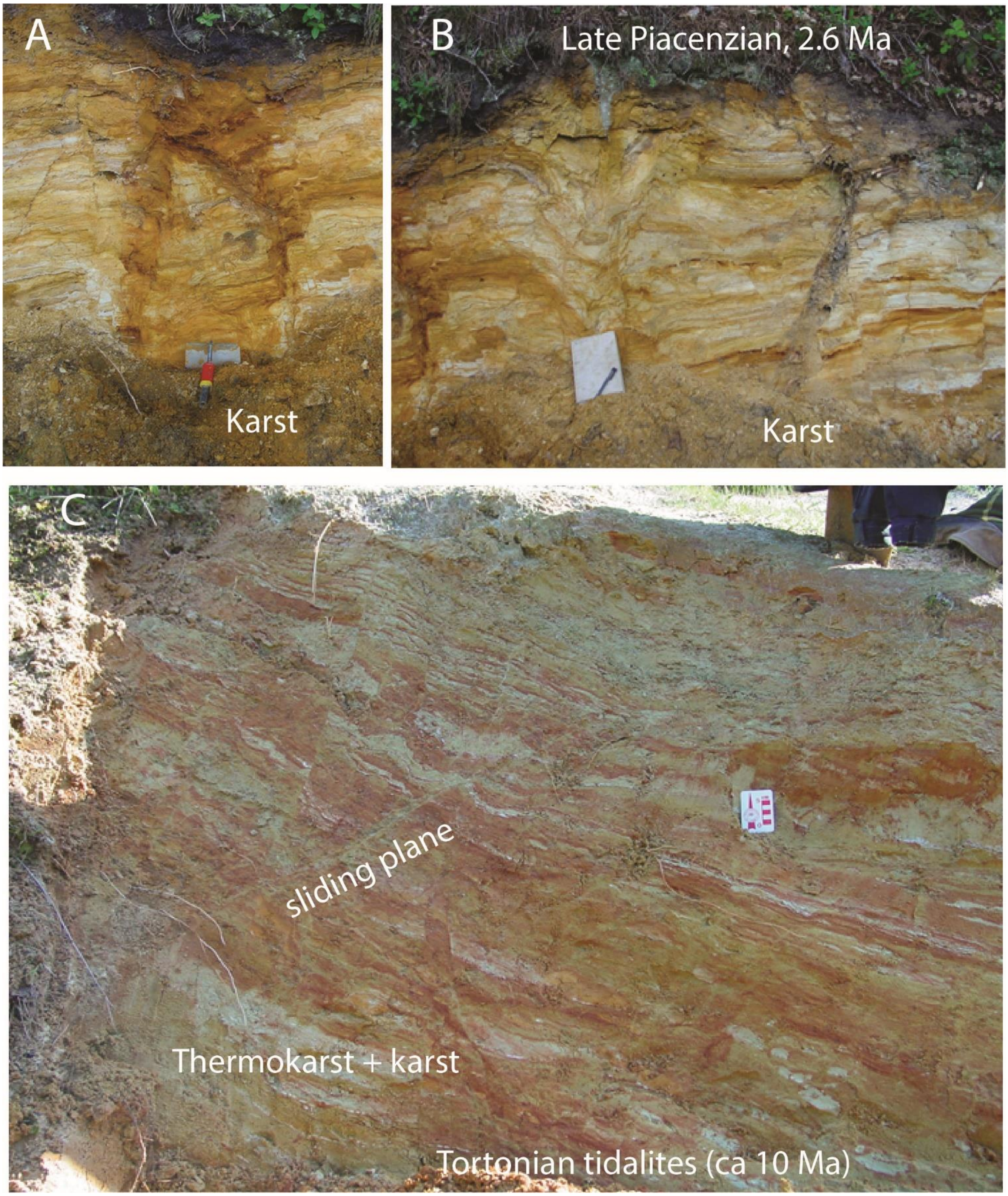

***Figure 16** : A) True cryoturbation's (Paris basin, on chalk). B) Cryoturbated Middle Pleistocene coastal ridge with frost jacked cobbles (Audierne Bay) ; C) Load casting due to karst activity triggered by an erathquake, Middle Terrace ; la Garenne des Andelys (Seine River); D) Middle Terrace, deformed and fractured pocket, above a known karstic pit. < 5 km of the Seine fault.*

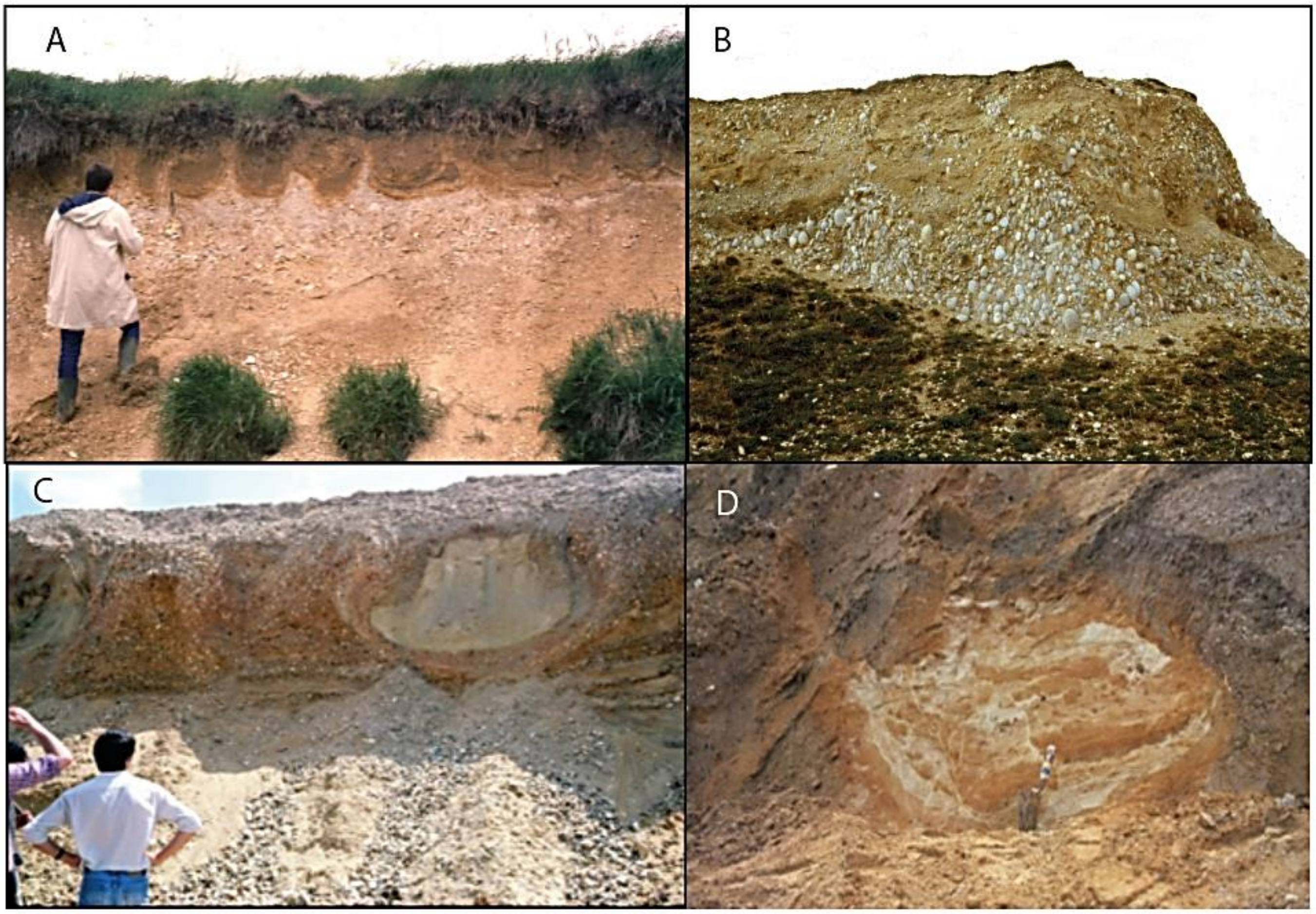

Figure 17** : **Saint Michel en Grèves : A) outcroping ductile cadomian crust (subducted; base of B) , disconnected from the onlapping discordant Ordovician (B) with a faulted contact (early Hercynian Orogen)

A

B