Towards establishing the petrogenesis of Miocene hydrocarbon seep-carbonates in southern Hawke's Bay, East Coast Basin forearc, New Zealand

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Abstract

This short account summarises some preliminary field and laboratory results from exposed Miocene hydrocarbon seep-carbonates in southern Hawke's Bay, East Coast Basin forearc. Both standard and cathodoluminescent petrography as well as stable oxygen and carbon isotope geochemistry have been conducted on a suite of rocks collected in the field. Reconnaissance work has identified a rich sedimentological and diagenetic history,, including multiple corrosion horizons, complex cements and veining, and polyphase microbial micrites commonly associated with botryoidal aragonite crystals that have distinctly negative $\delta^{13}C$ isotopic signatures. These seep-carbonates formed via microbially mediated, anaerobic oxidation of methane (AOM). A complete paragenesis is relevant to reconstructing the relative timing and nature of a variable fluid history archived in these methane-related deposits.

Keywords: *Petrogenesis, hydrocarbons, anaerobic oxidation of methane; seep-carbonates, Miocene; East Coast Basin, New Zealand*

Introduction

The convergent plate tectonic setting of the East Coast Basin forearc of North Island, New Zealand, affords not only a rare opportunity to study the migration of hydrocarbon-bearing fluids at modern-day onland and adjacent offshore cold-seep sites, but also at numerous, uplifted paleoseafloor sites archived within methane-derived authigenic carbonate deposits (MDACs) dating back to Early Miocene times. The ancient MDACs have variably depleted $\delta^{13}C$ isotopic values supportive of formation from the anaerobic oxidation of methane-rich fluids escaping at the paleo-seafloor, and they commonly include specialised chemosynthesis-based fossil communities.

This study, part of an integrated and multi-disciplinary Marsden funded collaborative project researching ancient seep deposits within East Coast Basin, focuses on newly discovered seep-related carbonate bodies and those recognised in earlier reconnaissance work but otherwise little documented (Campbell et al. in press). It aims to elucidate the complex geochemical, physical, and biological interactions operating at the ancient seep localities and to provide an overall temporal and spatial paragenetic sequence from which fluid-diagenetic pathway dynamics can be better understood within the wider context of the overall East Coast Basin geological setting.

Geological setting

These fossilised chemosynthesis-based ecosystems occur in two major geographic localities, one to the north of Gisborne in Raukumara Peninsula and the other to the east of Dannevirke in southern Hawke's Bay (Fig. 1).

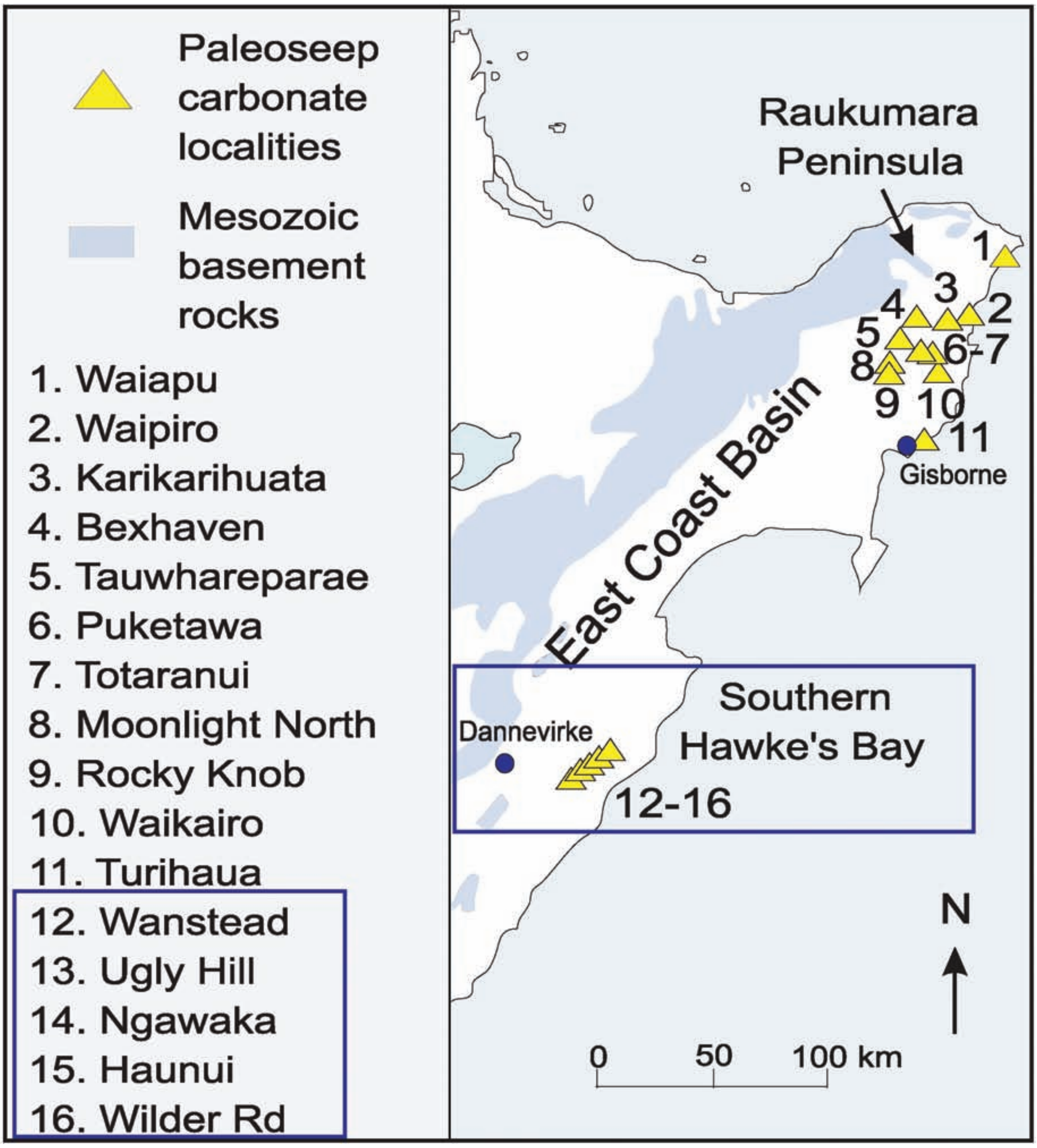

Figure 1. Paleoseep carbonate localities within the East Coast Basin, North Island. The southern Hawke's Bay boxed occurrences are the topic of this study.

In southern Hawke's Bay, five main, but localised, seep-carbonate fields (Ngawaka, Wanstead, Haunui, Wilder Road, Ugly Hill) have been identified over a distance of about 20 km, situated along strike on the western limb of the Akitio Syncline. They are hosted within the near basal deep-water mudstone and turbidite facies of the Early Miocene (Altonian) Ihungia Formation (of Lillie, 1953).

Seep carbonates in outcrop

In outcrop the carbonates commonly form unremarkable blocks, pods, lenses or mounds (Fig. 2A-E) and, in contrast to northern occurrences, are commonly associated with slightly coarser (sandier) siliciclastic host lithologies. Seep-dwelling benthic fossil assemblages are common, including coquinas of articulated lucinid and/or vesicomyid bivalve fossils and some mytilid mussels and corals (Fig. 3A-E).

The limestones exhibit major veining features and vugs, often cemented by different micritic types and methane-derived authigenic carbonate cements (Fig. 3F-H).

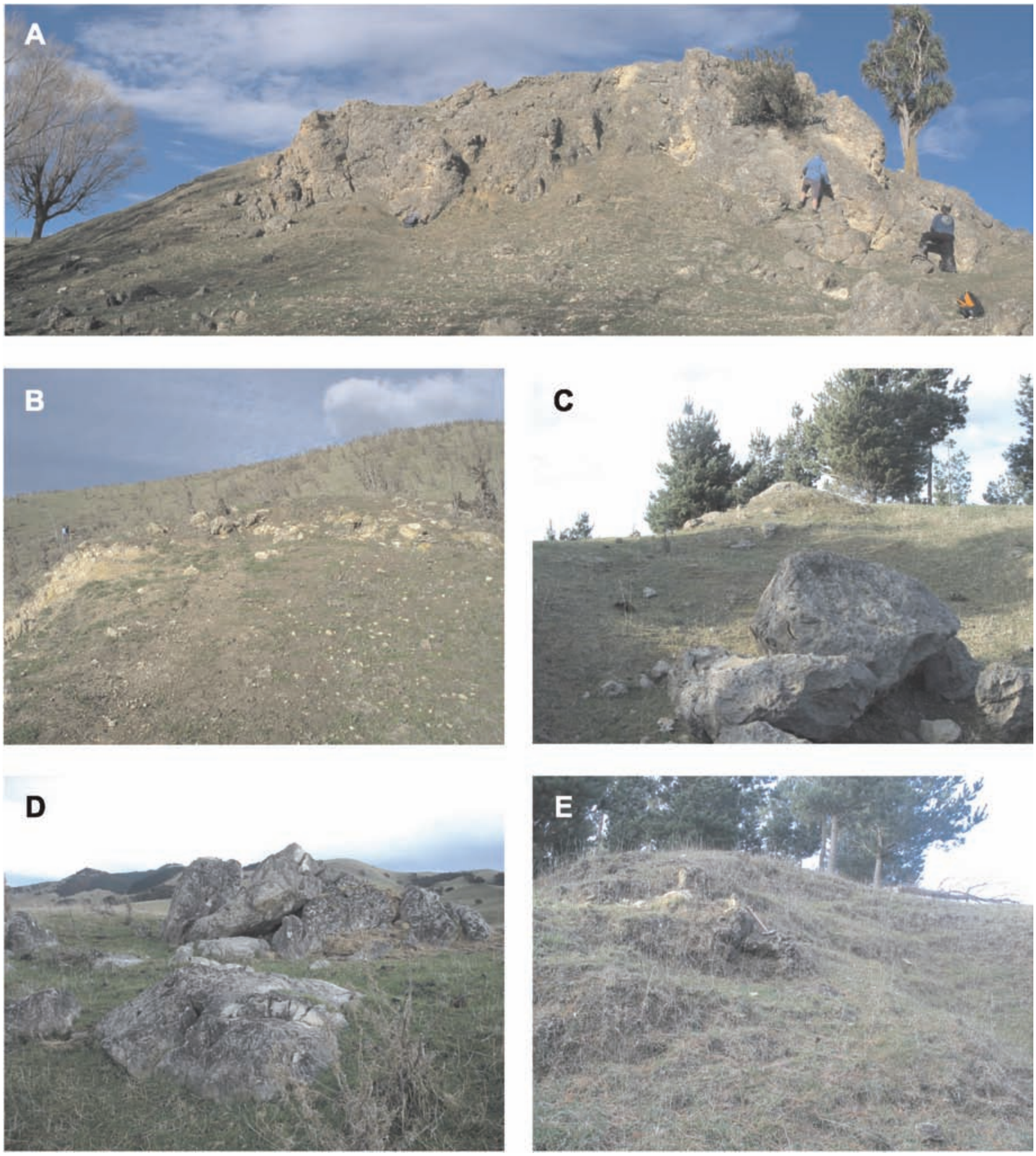

Figure 2. Seep limestones in outcrop. (A) Isolated hill-top outcrop of sandy seep-carbonate at Ngawaka. The site is marked by boulders ranging from small to large (>5 m) exposed across roughly 30 m of a rugged grassy hillside. The rocks are often conspicuously veined and exude a strong hydrocarbon odour upon sampling. (B) Scrappy outcrops of earliest Miocene fossiliferous seep-carbonate at Wanstead. (C) Sandy and fossiliferous outcrops of earliest Miocene seep-carbonate at Haunui form a prominent knoll. (D) Localised remnants of non-fossiliferous micritic MDAC-rich seep-carbonate at Wilder Road. (E) Isolated small outcrop of seep-carbonate at Ugly Hill.

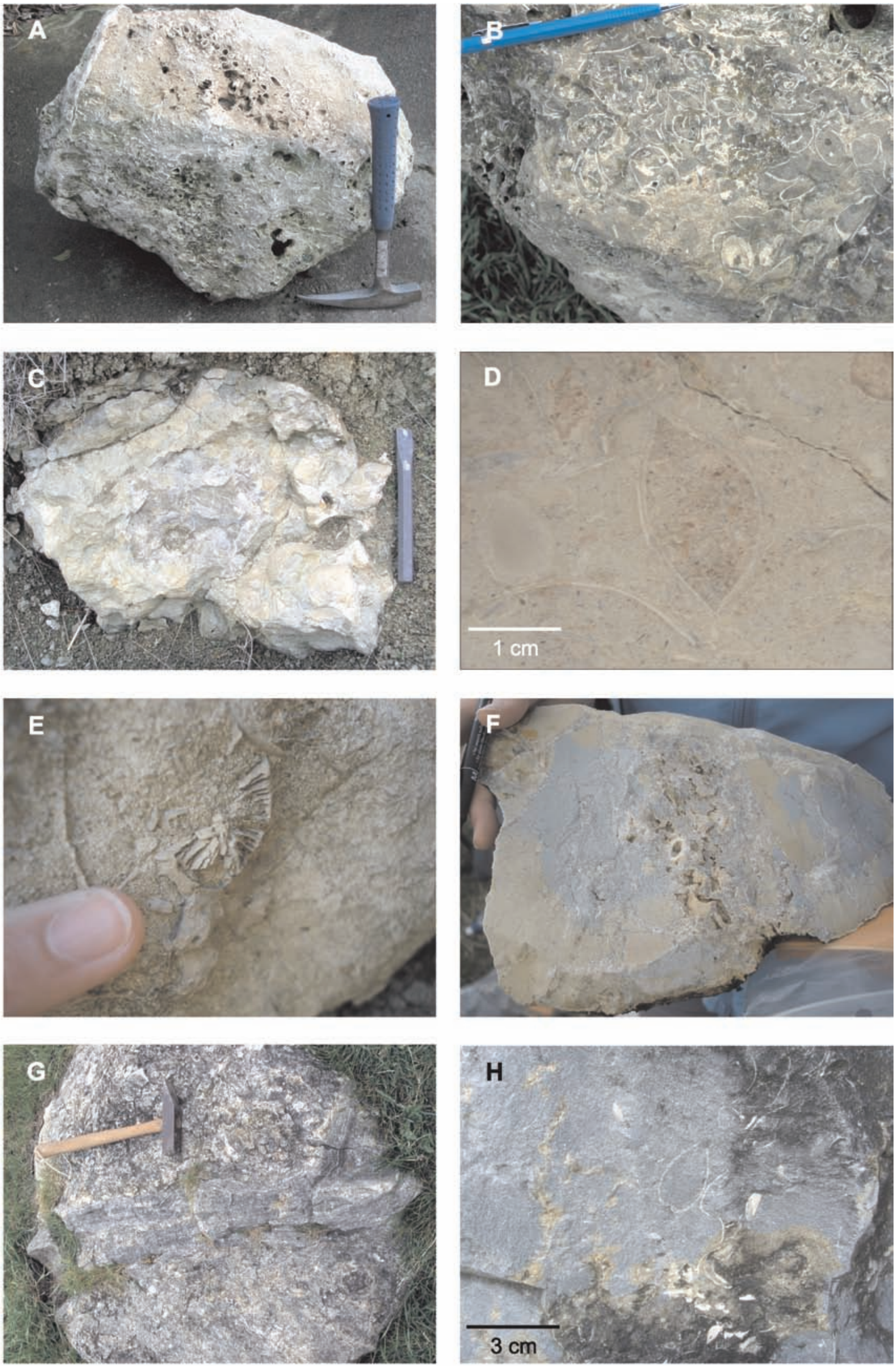

Figure 3. Fossils and veins in seep-carbonates. (A) Fossil-rich boulder of Early Miocene seep-carbonate at Ugly Hill includes mytilid and vesicomyid bivalves. (B) Seep-carbonate block containing typical bivalve biota, Ugly Hill. (C) Fossil mega-fauna (bivalves) within seep-carbonate outcrop block, Ugly Hill. (D) Slab of seep-carbonate showing bivalves in cross-section, Wanstead. (E) Coral (Goniocorella?) in seep-carbonate outcrop, Wanstead. (F) Freshly broken boulder of non-fossiliferous micritic brecciated and extensively vuggy seep-carbonate from Wilder Road. (G) Thick aragonite vein dissecting seep-carbonate boulder mid-section, Ngawaka. (H) Freshly broken surface of seep-carbonate with brownish-coloured authigenic carbonate.

Seep carbonates in thin section - an example from Wilder Road

A low-magnification thin section image of a Wilder Road seep-carbonate sample is shown in Fig. 4. Close-up images are shown in Figs. 5-7.

These rocks record complex histories including brecciation events followed by fracture healing by aragonite veins (Figs. 3G,H, 5C,D) reflecting multiple and often destructive fluid injection events. They can include micritic and wavy laminar structures suggestive of precipitation in microbial films and digitate growths (thrombolites) (Fig. 5A-D).

The carbonate mineral species (calcite, aragonite, possibly dolomite) (Figs. 5-7), tentatively identified from standard and cathodoluminescent petrography, formed via microbially mediated, anaerobic oxidation of methane (AOM), as evidenced by their typical seep-related textures (e.g., Beauchamp and Savard, 1992; Campbell et al., 2002; Peckmann et al., 2003; Conti et al., 2004; Campbell, 2006), and distinctly negative $\delta^{13}C$ isotopic signatures (Fig. 8), although they are comparatively less depleted than the northern seep-limestones (Campbell et al. in press).

Acknowledgments

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References

BEAUCHAMP, B. and SAVARD, M. 1992. *Cretaceous chemosynthetic carbonate mounds in the Canadian Arctic*. Palaios 7: 434-450.

CAMPBELL, K.A. 2006. H*ydrocarbon seep and hydrothermal vent paleoenvironments: past developments and future research directions. Palaeogeography, Palaeoclimatology, Palaeoecology* 232: 362-407.

CAMPBELL, K.A., FARMER, J.D. and DES MARAIS, D. 2002. *Ancient hydrocarbon seeps from the Mesozoic convergent margin of California: carbonate geochemistry, fluids and palaeoenvironments.* Geofluids 2: 63-94.

CAMPBELL, K.A.; FRANCIS, D.A.; COLLINS, M.; GREGORY, M.R.; NELSON, C.S.; GREINERT, J. and AHARON, P. (in press). *Hydrocarbon seep-carbonates of a Miocene forearc (East Coast Basin), North Island, New Zealand. Sedimentary Geology.*

CONTI, S., FONTANA, D., GUBERTINI, A., SIGHINOLFI, G., TATEO, F., FIORONI, C. and FREGNI, P. 2004. *A multidisciplinary study of middle Miocene seep-carbonates from the northern Apennine foredeep (Italy).* Sedimentary Geology 169: 1-19.

LILLIE, A. 1953. *The geology of the Dannevirke Subdivision. New Zealand Geological Survey Bulletin* 46: pp. 1-156. DSIR, Wellington.

PECKMANN, J., GOEDERT, J.L., HEINRICHS, T., HOEFS, J. and REITNER, J. 2003. *The Late Eocene 'Whiskey Creek' methane-seep deposit (western Washington State): part II. Petrology, stable isotopes, and biogeochemistry.* Facies 48: 241-254.

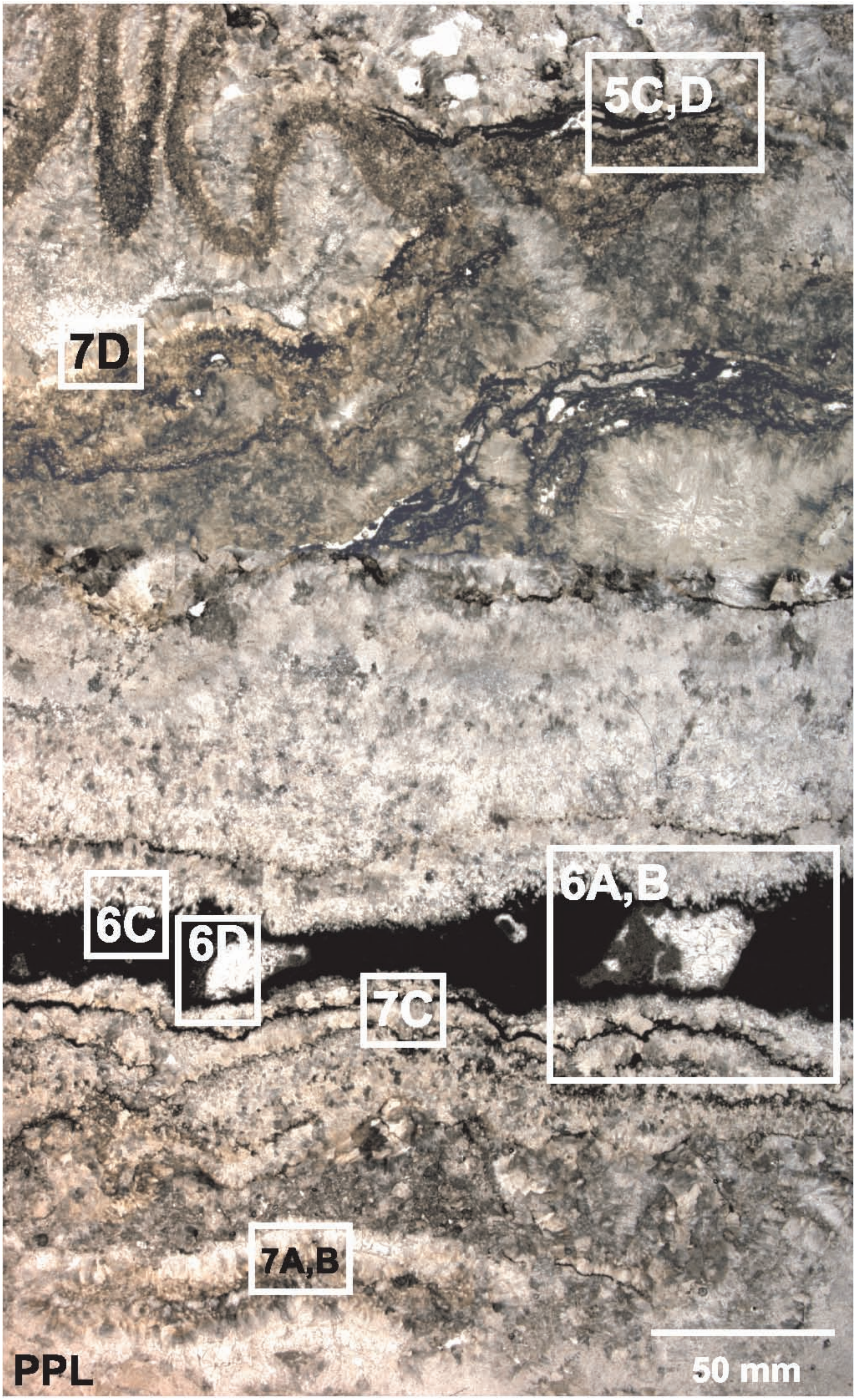

Figure 4. Entire thin section view of seep-carbonate from Wilder Road, southern Hawke's Bay. Boxes and letters show positions of some of the higher power images in Figs. 5-7. PPL = Plane polarised light.

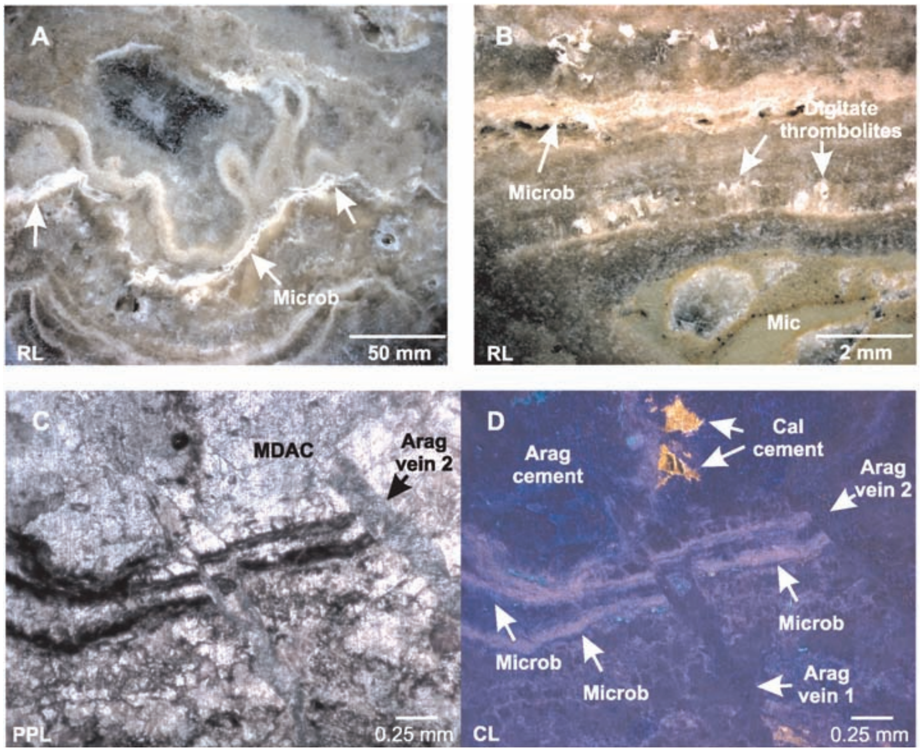

Figure 5. Microbialite films/thrombolites. These appear in (A) and (B) under incident light as white films (arrowed). Photo pair in (C) and (D). In (C) they appear as dark films under PPL with same view in (D) showing a pink/blue luminescence under CL. Microb = Microbialite films; Arag = Aragonite; Cal = Calcite; Mic = Micrite; PPL = Plane polarised light; CL = Cathodoluminescent light; RL = reflected light.

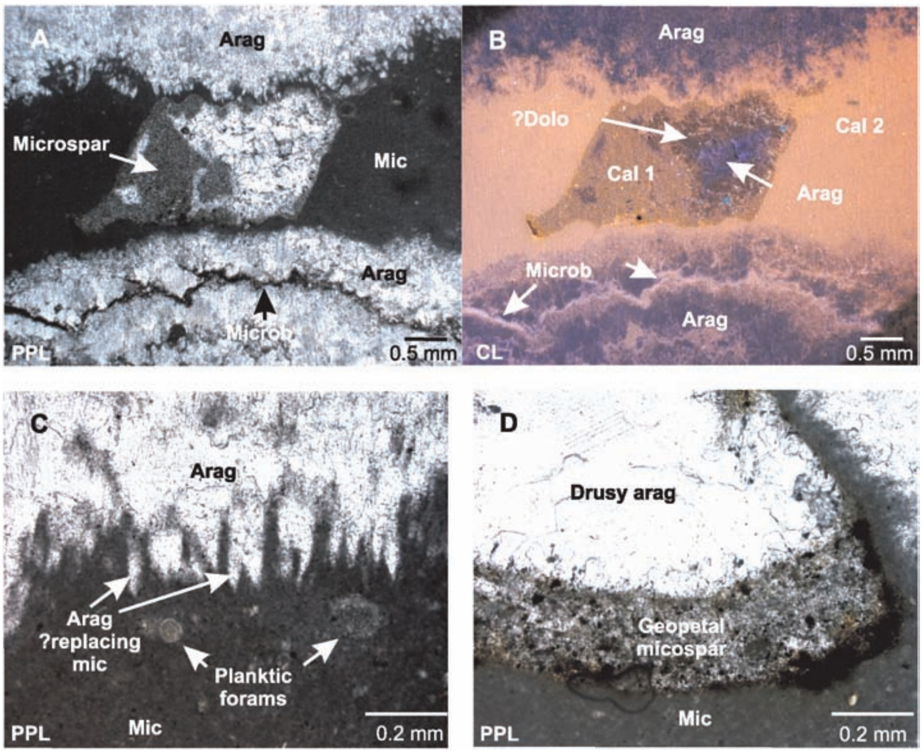

Figure 6. Corrosion and replacement features. Photo pair in (A) and (B) of corrosion cavity in micrite sediment infilled by a complex array of mineral types. (C) Foram-bearing sediment being ?replaced by aragonite spar which exhibits a bright blue luminescence under CL light (not shown). (D) Geopetal, pyrite-bearing microspar infilling corrosion vug within micrite sediment. Microb = Microbialite films; Arag = Aragonite; Cal = Calcite; Dol = Dolomite; Mic = Micrite; PPL = Plane polarised light; CL = Cathodoluminescent light.

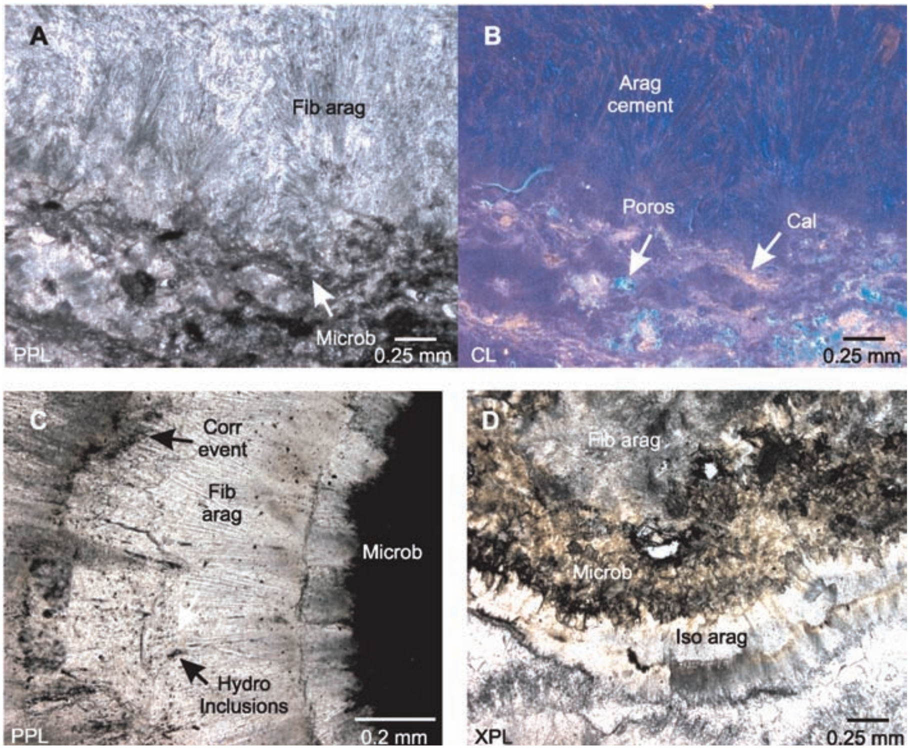

Figure 7. Hydrocarbon-bearing authigenic aragonite. Photo pair showing details of radially fibrous aragonite in PPL in (A) and CL in (B) indicative of rapid early sea floor formation upon thrombolites near vent-fluid conduit areas. Blue is the characteristic CL signature of aragonite while pink/orange is likely calcite. (C) Inclusion-rich zone (dark patches/blebs inferred to be hydrocarbons) within bundles of radiating fibrous aragonite cements. (D) Undulose extinction of acicular aragonite bundles within multiple isopachous, commonly yellowish, anhedral, dark inclusion-rich cements (cf. Beauchamp and Savard, 1992). Microb = Microbialite films; Arag = Aragonite; Por = Porosity; Corr = Corrosion; Cal = Calcite; Fib = fibrous; Hydro = Hydrocarbon-bearing; Iso = Isopachous; PPL = Plane polarised light; XPL = Cross polarised light; CL = Cathodoluminescent light.

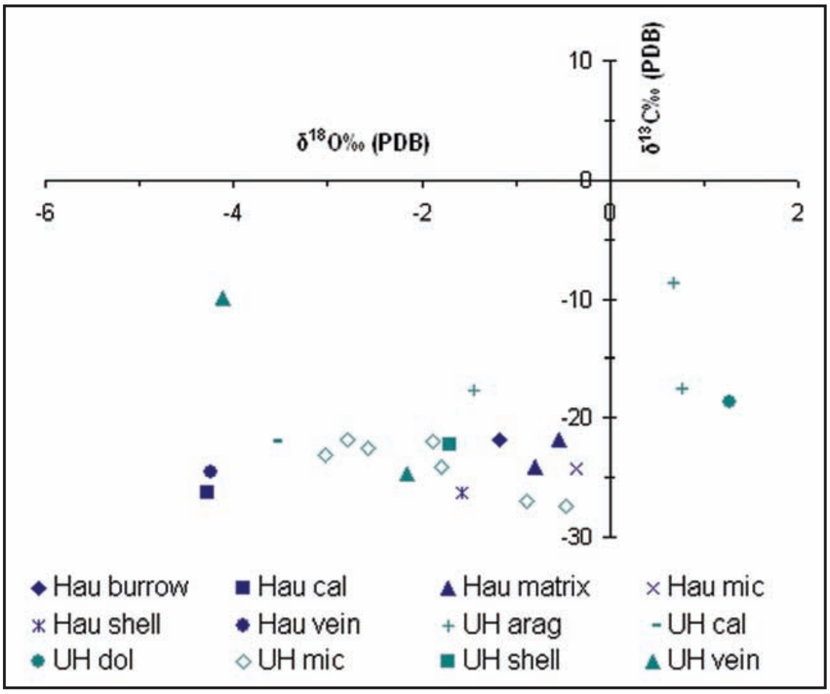

Figure 8. Stable O and C isotope plot of samples from Haunui (Hau) and Ugly Hill (UH) showing depleted $\delta^{13}C$ values of -20 to -30‰ supportive of formation by microbially mediated, anaerobic oxidation of methane (AOM). Cal = calcite; dol = dolomite; mic = micrite.