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1 **Mineralogy and genesis of the lateritic regolith related Ni-Co deposit of the**
2 **Çaldağ area (Manisa, western Anatolia), Turkey**

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13 **Abstract:** The Çaldağ Ni-Co deposit is characterized by a reddish-brown oxide
14 lateritic regolith, containing residual Ni deposit formed by the intense tropical
15 weathering of peridotites. Nickel-Co ore is associated with transported ferricrete
16 during the Late Paleocene-Middle Eocene, represented by colloform Fe oxides and
17 residual lateritization during the Oligocene. The lateritic regolith are developed over
18 dunitic ultramafic rocks and consist mainly of smectite, berthierite, kaolinite, gypsum,
19 pyrite, takovite, and pecoraite. These units were examined using polarized-light
20 microscopy, X-ray diffraction, scanning and transmission electron microscopy and
21 geochemical methods. Mineralogical zonation from the base of the profile upwards
22 has the following zones: ultramafic bedrocks; serpentinized ultramafic rocks
23 (saprock), saprolite, carbonate- and sulfide-bearing zone, ferruginous saprolite zone,
24 and silcrete. In addition, Fe oxides, smectite and opal-CT, and quartz increase
25 towards the surface, whereas olivine, pyroxene and serpentine decrease upwards in
26 response to chemical weathering. Nickel-Co mineralization associated with Fe oxides

and smectitic clays formed under wet and dry conditions, respectively, as a result of an increased $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3 + \text{Ni} + \text{Co} / \text{MgO}$ ratio. Field observations, mineralogical and geochemical analyses reveal that the smectite formed under basic conditions was controlled by multistage chemical weathering of ultramafic and volcanic rocks, and the concentration of Si, Al, Fe, and Mg. Locally, concentration of S in conjunction with Fe and Ca resulted in precipitation of goethite/hematite, gypsum and pyrite in dissolution voids in association with smectite under acidic conditions that developed in a well-drained system.

Keywords: Lateritic regolith deposit, Ni-minerals, Smectite, Ultramafic rock, Çaldağ, Turkey.

Introduction

In the Turgutlu (Manisa) area of western Turkey, the Çaldağ lateritic deposit has a Ni-Co reserve of approximately 38,000,000 metric tons (Yıldız, 1977, 1982, 1994). The deposit within regolith developed on ultramafic rocks. The primary Ni-bearing ore phases in serpentinized peridotites is pentlandite; the mean grade of the serpentinized ultramafic rocks (saprocks) is 0.2–1.2 wt.% Ni; 0.04–0.11 wt.% Co. The regolith comprises ferruginous saprolite and clay rich saprolite zones (0.02–5.6 wt.% Ni; 0.02–5.2 wt.% Co), locally associated with thin greenish garnierite layers, a carbonate- and gypsum-bearing zone (0.2–1.2 wt.% Ni; 0.04–0.11 wt.% Co), and a silica-rich zone (0.2–1.2 wt.% Ni; 0.04–0.11 wt.% Co). The different Ni-Co contents have been estimated through field work, diamond drilling data and geochemical exploration, as well as through information provided by the General Directorate of Mineral Research and Exploration of Turkey (MTA), the European Nickel Company

52 (www.enickel.co.uk) and Helvacı et al. (2008). At present, the Çaldağ Ni-Co deposit
53 is owned and handled by the Çaldağ Nikel Company.

54 Nickel-Co lateritic regoliths are supergene deposits of Ni±Co formed by
55 pervasive chemical and mechanical weathering of ultramafic rocks. The formation of
56 secondary concentrations of Ni±Co substantial enough for an economic resource
57 requires a source rock that is primarily enriched in Ni. Nickel lateritic regolith deposits
58 are mineralogically complex, discontinuous, and commonly have Ni enrichment in
59 more than one regolith zone of the weathering profile zones (Lelong et al. 1976; Butt
60 1979; Butt and Nickel 1981; Brand et al. 1998; Elias 2001a, 2001b; Gleeson et al.
61 2003). They are the product of prolonged and pervasive mechanical and chemical
62 weathering of harzburgite, dunite, and peridotites and their metamorphic derivatives,
63 such as serpentinized ultramafic rocks. Some deposits have been subsequently
64 mechanically weathered, redeposited, reconcentrated, and possibly covered by
65 younger sediments (Golightly 1981; Butt and Cluzel 2013).

66 One of the most important factors in forming Ni-Co lateritic regolith deposits is
67 the degree of permeability of the parent material (Norton 1973; Brand et al. 1998).
68 Faults, fractures, joints and cleavage thus play a key role in Ni-Co lateritic regolith
69 mineralization increasing the permeability of the protolith. Structure controls both Ni
70 mineralization and weathering (Pelletier 1996).

71 To date, the region has been studied mainly in terms of the geology of the Ni-
72 Co deposit (Yıldız 1977, 1982, 1994; Helvacı and Şahin 1981; Helvacı et al. 2007,
73 2008, 2013; Tavlan et al. 2011), the mineralogy of Ni-Co deposit (Cöcen 1980;
74 Çağatay et al. 1981; Yıldız 1982, 1994; Thorne et al. 2009; Tavlan et al. 2011;
75 Helvacı et al. 2013), and the underlying Late Cretaceous – Early Paleocene ophiolitic
76 complex (Erdoğan 1990; Okay and Siyako 1993; Kaya et al. 2004; Figs. 1–3). The

geology, lithology, mineralogy, chemistry and history of the occurrence of lateritic regolith ore phases have been also studied by Thorne et al. (2009) and Tavlan et al. (2011), but those contributions do not include detailed study on the clays of the lateritic Çaldağ Ni-Co deposit. Thorne et al. (2009) describes the results of mapping combined with mineralogical investigations of separate profiles located within the Çaldağ deposit and the major formational processes within the deposit. Tavlan et al. (2011) combines known ages of ophiolite exposure with associated palynological, paleoenvironmental and paleoclimatic studies, and field studies in the Çaldağ area in order to establish the weathering history of western Turkey.

The present study is focused on the geology, new contributions regarding mineralogy, micromorphology, and geochemistry of the lateritic regolith deposit, which developed in a tectonically-controlled system within the ultramafic rocks; it emphasizes and highlights the lateritic weathering of peridotites based on intensive field study. We also provide new data and explain the physicochemical conditions of lateritization and the genesis of the lateritic regolith and associated clays and Fe oxides developed on ultramafic rocks in other deposits in western Anatolia which have yet to be studied. Over all the main concern of this paper is focused on interpretation of the mineralogical and chemical data of Ni-Co-bearing clays and their relation with the lateritization processes in the Çaldağ lateritic regolith deposit. These findings have particular importance in relation to the exploration for similar lateritic regolith systems and deposits worldwide.

Regional geology

Anatolia comprises two main continental assemblages, the Sakarya continent of the Pontides to the north and the Anatolide-Tauride block to the south. These

continents were amalgamated during Late Cretaceous – Paleocene convergence and continental collision along the northern branch of the Neo-Tethys, which is marked by the İzmir-Ankara-Erzincan Suture Zone (İAESZ) (Şengör and Yılmaz 1981; Okay and Siyako 1993; Kaya et al. 2004; Ersoy et al. 2014). The İAESZ in western Anatolia is represented by the ophiolitic mélange units of the Bornova Flysch Zone, and was formed by Late Paleocene to Early Eocene closure of the northern branch of the Neo-Tethys Ocean between the Sakarya continent and the Anatolide block; the latter includes the Menderes Massif and the Lycian Nappes (Şengör and Yılmaz 1981; Erdoğan 1990; Erdoğan et al. 1990; Okay and Siyako 1993; Okay et al. 1996, 2001).

The pre-Miocene basement is characterized by the Bornova Flysch Zone (BFZ), (Erdoğan 1990; Okay et al. 2012), an olistostrome–mélange belt, lying between the Menderes Metamorphic Core Complex and the Sakarya zone, as part of the İAESZ. The BFZ is defined as a tectonic belt on the northwestern margin of the Anatolide-Tauride Block (Okay and Altiner 2007; Okay et al. 2012), and is composed of an extremely deformed and locally metamorphosed flysch-like sedimentary matrix of a Maastrichtian–Paleocene age, with blocks of Mesozoic limestones, serpentinized ultramafic rocks and submarine mafic volcanic rocks (Erdoğan 1990). The BFZ is represented by saprock and spilitic volcanic rocks with a pelagic matrix, and has a maximum width of 90 km and a length of ~230 km, defining a tectonic zone between the Menderes Massif and the İAESZ. The blocks in the BFZ generally consist of Triassic, Jurassic and Cretaceous marine limestones. The flysch and the blocks are unconformably overlain by undeformed late Early Eocene neritic limestones.

The Çaldağ lateritic regolith deposit is developed on ultramafic rocks of the Late Cretaceous – Early Paleocene ophiolitic mélange of the BFZ, located on the

northern edge of the Menderes Massif, within the Gediz Graben (Figs. 1, 2). The deposit lies on the Çaldağ horst of the Gediz Graben and covers approximately 10 km² (Figs. 1, 2). The Çaldağ mineralization shows complex and zoned structures and resembles residual Ni deposit formed by intense tropical weathering and lateritization of peridotites, which contain economical amounts of Ni (0.2–1.2 wt.% Ni).

During the Pliocene–Quaternary period, the western Anatolia was dissected by high-angle normal faults resulting in NW–SE trending horst - graben structures. The E–W-trending Gediz graben is one of the most prominent features of western Turkey. It is an actively growing asymmetric graben, with the normal faults mainly located on the seismically more active southern margin. The Çaldağ horst was developed in the northern margin of the Gediz Graben (Figs. 1, 2) and Plio–Quaternary alluvial fans formed around the Çaldağ horst due to erosion of the rising blocks (Kaya et al. 2004; Bozkurt and Sözbilir 2004; Çiftçi and Bozkurt 2009, 2010).

Lateritization has occurred during the Middle to Late Eocene (Okay and Siyako 1993; Okay et al. 1996; Tavlan et al. 2011). The Çaldağ ophiolite was exposed to weathering only from the Mid-Paleocene to the Late Miocene and from the Mid-Pliocene until the present (Fig. 3; Okay and Siyako 1993). The ophiolite was exposed and eroded prior to deposition of the Eocene Başlamış Formation confirming that emplacement of ophiolites took place in the region. This means that the timing of ophiolite exhumation is constrained by both tectonics and sedimentation processes (Akdeniz 1980; Okay and Siyako 1993; Okay et al. 1996; Önoğlu 2000).

The Çaldağ lateritic regolith is locally overlain by Neogene terrestrial sediments, which can be grouped into three contrasting lithological associations, the Develi, Halitpaşa and Kızıldağ formations shown as Neogene terrestrial sediments in the generalized Çaldağ stratigraphic column (Fig. 3). The Develi Formation is the

lowermost unit of the Neogene terrestrial sediments and unconformably overlies the pre-Paleocene basement rocks.

The Late Cenozoic events in the Çaldağ area can be summarised as follows: (1) Late Miocene to earliest Pliocene lacustrine deposition (extension); (2) Earliest Pliocene major unconformity (compression); (3) Late early Pliocene restricted lacustrine deposition (extension); (4) Late Early Pliocene truncational erosion and tilting of the late lacustrine deposits; and late Early Pliocene to Late Pliocene continuum of distal alluvial-fan deposition (extension) (Kaya et al. 2004).

Analytical methods

In order to identify the distribution of lateritization in the Ni-Co Çaldağ deposit nearly 200 samples, representative of the various lateritic regolith types along stratigraphic sections were collected. The samples were analyzed for their mineralogical characteristics by polarized-light microscopy (Leitz Laborlux 11 Pol), X-ray diffractometry (XRD) analysis at the Texas Technical University (Texas, USA) and Dokuz Eylül University (İzmir, Turkey) using Philips X'Pert Pro diffractometer instruments.

X-ray diffraction analyses were performed using $\text{CuK}\alpha$ radiation at a scanning speed of $1^\circ 2\theta/\text{min}$ and a tube voltage and current of 40 kV and 30 mA, respectively. Samples for clay analysis ($< 2 \mu\text{m}$) were prepared by separating the clay fraction by sedimentation and centrifuging the suspension after overnight dispersion in distilled water. The clay particles were dispersed by ultrasonic vibration for ~ 15 min. Oriented specimens of the $< 2 \mu\text{m}$ fractions were prepared from each sample by drying with air, and solvating with ethylene glycol at 60°C for 2 hours. Semi-quantitative amounts of rock-forming minerals were obtained with Brindley's (1980) external standard

method, whereas the relative abundances of clay-mineral fractions were determined using their basal reflections and mineral intensity factors (Moore and Reynolds 1989).

Scanning electron microscopy – energy dispersive spectroscopy (SEM-EDS) studies were performed at the Dokuz Eylül University (İzmir, Turkey) using a JEOL 6060 instrument. Representative lateritic regolith bulk samples were prepared for the SEM-EDS analyses by adhering the fresh, broken surface of each rock sample onto an aluminum sample holder with double-sided tape. The samples were then coated with a thin film (~ 350 Å) of gold using a Giko ion sputter.

The clay fractions of eight lateritic regolith samples were examined with XRD diffraction (XRD) and scanning transmission electron microscopy (STEM) in imaging mode and EDS spectral analysis of the main elements at the Texas Tech University (USA). The clay particles for STEM analysis were dispersed in an ultrasonic ethanol bath for approximately 30 min, and one drop of each clay suspension was placed on a carbon-coated copper grid and dried at room temperature.

Sixty serpentinized ultramafic rocks and lateritic regolith bulk samples were chemically analysed for major- and trace elements at Acme Analytical Laboratories Ltd. (Vancouver, Canada) using inductively coupled plasma–atomic emission spectroscopy (ICP-AES) PerkinElmer (Elan 9000) (USA). The Spectro XLAB-2000, PEDX-ray fluorescence spectrometer was calibrated using USGS standards. The ICP-AES analyses were carried out on lithium metaborate/tetraborate fusions following digestion in dilute nitric acid. Loss on ignition (LOI) was determined as the weight difference after ignition at 1000°C . The detection limits for the analyses were between 0.01 and 0.1 wt.% for major elements and between 0.1 and 5 ppm for trace elements.

The structural formulae of serpentine, smectite, and berthierine were determined for the $<2\ \mu\text{m}$ clay samples with the largest serpentine, smectite, and berthierine contents (confirmed by XRD). The samples were then analyzed by ICP-AES at Acme Analytical Laboratories Ltd. (Vancouver, Canada). The structural formulae of serpentine, smectite, and berthierine were calculated on the basis of 14, 22, and 14 oxygen atoms, respectively (Moore and Reynolds, 1989).

Results

Detailed geology of main lateritic regolith deposit

Stratigraphy of the lateritic regolith

Weathering advances in the upper, more intensely weathered zones of the profile, the chemical and mineralogical compositions, and fabric are entirely different from the parent rock (Elias 2001a,b). The lateritic regolith profile in the Çaldağ deposit displays the following zones from bottom to top: (1) Ultramafic bedrock zone; (2) Saprock and saprolite zones; (3) Ferruginous saprolite zone; and (4) Silcrete zone (Figs. 4, 5).

Ultramafic bedrock zone

Ultramafic and basic rocks of the upper Cretaceous ophiolites are up to 200 m thick in the study area. The ultramafic rocks are represented by peridotites and pyroxenites. The peridotites are encountered in the northwest part of the Upper Pits (Doktor Pit). They are altered, and light-dark green, yellow or brown in colour. Olivine crystals are clearly observed on the fresh surfaces of the peridotites and thin bands

of chromite are seen within the peridotites. Magnesite has generally filled the dense networks of fractures in the peridotites. The pyroxenites, which outcrop both on the northern and southern parts, are occasionally fragmented and have a massive appearance. Most of the pyroxenites show various tones of green and yellow, and are likely to have been serpentinized.

Saprock and saprolite zones

The serpentinized ultramafic rocks are generally 3–4 m thick, and rarely exceed 100 m. The lateritic regolith are yellowish and brown and contain zones with elevated contents of Fe, Ni and Co. They show a gradual transition from brownish saprock at the bottom to the reddish brown ferruginous saprolite above. In the upper part of serpentinized units, Fe oxide zone shows evidence of a mesh structure suggesting that it is partly characterize saprolite, often left remnants of spheroidal weathering, that can be found up to 2–3 m. The ferruginous saprolite zone enriched in Ni is generally 2–3 m thick, and rarely over 30–40 m. Dark brown or black hematite is abundant in the upper part of the ferruginous saprolite zone.

In the gradual transition from serpentinized to ferruginous saprolite zones, there are clay bands with colours of green, blue and lilac. The Ni grade within these clay bands is rather low. However, the soil-like serpentinized zones, whose thickness ranges from 1–2 m to 15–20 m, contain higher Ni grades, and cracks have been filled with coarse calcite crystals. Since they show discontinuities both laterally and vertically, their contact with the serpentinized zone is sudden and sharp. The major elements of ultramafic rocks, namely Mg, Fe, Mn, Ni, and Co have been largely removed by extreme physical weathering and chemical alteration are concentrated in the saprock. Fe^{2+} is oxidized to Fe^{3+} and sedimented at suitable morphologies over

the saprock in the form of $\text{Fe}(\text{OH})_3$. The thickness of the ferruginous saprolites is 5–50 m depending on the paleomorphology; it can increase to 100 m in deep basins and fractured zones. Although the profiles within the deposits are broadly similar, there are marked local variations in fabric, morphology, and mineralogical composition (Fig. 4a–h). The boundary between the ferruginous saprolite and serpentinized zone below is sharp with a marked decrease of MgO. Nickel concentrations within goethite, the main ore mineral, reach a maximum of ~3 wt.% near the base of the ferruginous saprolite zone. The identification of transportation mechanisms which may have modified the Çaldağ lateritic regolith during formation is crucial to the understanding of the present-day deposit morphology. Transportation mechanisms that produce transported ferricrete include erosion, slumping, and fault-related movement (Fig. 4d–g). The lateritic regolith has been modified by deformation and surface processes during and after its formation.

Ferruginous saprolite zone

The ophiolite in the Çaldağ area would have been exposed and influenced by tropical-subtropical climatic conditions for only short periods during the Eocene - Miocene erosional phases. After the formation of a regolith including the Ni-bearing ferruginous saprolite zone, the Çaldağ mélange was completely and unconformably overlain by Pliocene sediments. Boundaries between saprock and the saprolite, ferruginous saprolite zones are structural and the degree of serpentinization is controlled by the intensity of shear zones in these peridotites. There are numerous instances of *in situ* boundaries across the deposit with meter scale interdigitation of serpentine and smectite rich clay as well as goethite veinlets (Fig. 4a–g). In the Çaldağ mine, Upper Triassic dolomitic limestone occurs at the base. Over this are

found Late Cretaceous ultramafic and basic rocks. In the top of the section, Pliocene sediments such as clayey limestone, conglomerate, claystone unconformably cover the other units. Quaternary cover is rare, especially at higher elevations.

Silcrete zone

The silcrete zone formed at the uppermost in the sequence of the lateritic regolith profiles (Fig. 4a,c,d). Silcrete zone mostly overlain ferruginous saprolite zone. This crust, whose surface is uneven, nodular and hard, covers the other zones like a shield and is some 50–60 m thick. The zone is formed by released silica during chemical weathering of ultramafic units resulted precipitation of quartz and opal-CT.

Open pit mines of the Çaldağ lateritic regolith deposit is described below:

Doktor Ni-Co Pit (Hematite)

The Doktor Pit is located in the northernmost part of the study area at an elevation of approximately 1000 metres (Fig. 4a–c,h). In the lateritic regolith profile the following zones were identified from bottom to top: saprock zone, a saprolite zone which is present locally throughout the pit, with a ferruginous saprolite zone (Fig. 5). A description of each zone is as follows.

Saprock: One hundred metres southwest of the Doktor Pit, the least serpentinized ultramafic rocks comprise dunite and harzburgite with pyroxenite bands. Saprock formed by weathering of the ultramafic bedrock surface (Figs. 2, 4a–c).

Saprolite zone: Field observations identified two distinct saprolite zones, a bluish-green, Ni-rich zone associated with the original weathering profile and a green, Ni-poor zone formed along the thrust plane within the upper levels of the lateritic

regolith profile. The Ni-rich saprolite zone extends horizontally between the hard saprock and the ferruginous saprolite zone for a few tens of meters with a thickness of up to 40 cm (Fig. 4a–c). The highest Ni grade in the saprolite zone varies from ~ 1 to 2 wt.%. The limited thickness of both saprolite zones indicates a humid tropical environment, which favours the leaching and removal of silica during the weathering of ultramafic rocks and formation of goethite in an acidic (pH) 3–3.5 environment, rather than the formation instead of lateritic clay (smectite), which requires poorer drainage restricting leaching and basic environment close to top of saprolite. This explains the silica concentration increases upward in the sequence of the profiles, as it can not be locked up in the formation of clays.

Ferruginous saprolite zone: The lateritic profile ranges in thickness between 10 and 25 metres (Fig. 4a–c). A dense network of goethite in stringers and veinlets penetrates through the clay-rich saprolite zone.

North Ni-Co Pit

The lateritic zone (ferricrete) was transported over the saprock by the thrust fault striking N70W and dipping 15–25° to the South (Figs. 2, 4d,g). The complex, irregular internal structure of the ore body is the result of faulting and inversion during transportation of ferricrete after lateritization (Fig. 4d,g). At the bottom of the section the transition from saprock to ultramafic bedrock can be observed clearly (Fig. 4i). Saprock is tectonically overlain by a 15–30 cm thick saprolite zone associated with the thrust plane. The smectite rich saprolite zone varies from yellowish to orange-brown; goethite is associated with a thin greenish garnierite layer at the contact of the Mn-bearing ferruginous saprolite zone (Fig. 4j,k,l,m). Over the saprolite zone at the bottom of the lateritic regolith profile, highly fractured lateritic regolith consists largely

of goethite and has a thickness of up to 0.5 meters. Lateritic blocks of different sizes are cemented by mixed of Fe oxides, carbonates, takovite, and gypsum between 0.5 and 2.5 meter thick derived from a carbonate- and sulfide-bearing zone (Figs. 4n, 5). The abundance of Fe oxides and carbonate plus gypsum decreases towards the upper portion of the section. The upper portions of the section contain blocks of limestone and gypsum up to a few tens of metres in diameter.

South Ni-Co Pit

The South Pit is located in the lowest topographical level among the three open pits and contains the thickest lateritic regolith ore (Figs. 2, 4e,f). Most of the lateritic regolith in the Doktor, North, and South Pits were eroded and transported as ferricrete downhill to the lower parts by either water, downward sloping or vertical-slip faults (Figs. 2, 4d–h). Field studies indicated that normal faults have been reworked as reverse faults due to compressional reactivation processes and transportation of ferricrete (Fig. 4e,f). Saprock is overlain tectonically by a thick, lateritic regolith profile comprised mainly of goethite, hematite and clay in order of increasing abundance (Fig. 4e,f). Both vertical and lateral boundaries between saprock and saprolite are fault-controlled in the South Pit. At the bottom of the ferruginous saprolite, goethite-dominated ore is dark brown to black in colour and occurs as massive, crystalline ore with banding fabrics. The dark facies of the lateritic regolith is made up of aggregates of goethite, hematite and asbolane. Nickel-bearing minerals associated with gypsum and calcite in the fractures of goethite includes bright green takovite (Fig. 4n). In the sections and open cut pods and thin layers, up to a few decimeters thick, of plastic clays were identified. Oxidation of pyrite and hematitization of goethite are the most common processes of weathering in the South Pit. Goethite-dominated zone passes

gradually to overlying hematite-bearing Fe oxides that transition upward to carbonate due to recent surficial weathering of the overlying units. These units are also associated with nodular and layered gypsum that formed within the weathering zone. The lateritic regolith profile in the South Pit is unconformably overlain by Upper Miocene - Lower Pliocene lacustrine sediments, which are probably the source of the carbonates.

Mineralogical and chemical analyses

Petrography

The ophiolitic complex in the study area comprises dunite, harzburgite, basaltic pillow lava and radiolarite. Dunite samples exhibit poikilitic fabric and consist of > 90% olivine and 2–5% pyroxene (Fig. 6a,b). Olivine crystals exhibit anhedral forms and are serpentinized along fractures (Fig. 6c). Fe oxide phases and calcite are strongly developed in ultramafic bedrocks of the deposit which locally include euhedral to subhedral grains of disseminated chromite (Fig. 6a) 1.5–2 mm in size, with a cataclastic fabric and associated with alteration minerals.

Intense weathering of the ultramafic rocks resulted serpentinization and consequently lateritization. Goethite and hematite are abundant, and pyrite scarce, in serpentinized and lateritized ultramafic rocks (Fig. 6c,d). Green, yellow and brown serpentinized and silicified ultramafic rocks (dunite) enclose magnesite and stockwork-type, fracture filling calcite and silica resembling saprolite (Fig. 6c,d). Goethite and secondary quartz and relict chromite occur in dissolution voids within the silicified breccia in ultramafic bedrock of the Doktor Pit. This serpentinized and highly altered zone has a Ni grade of 0.2–1.2 wt.% Ni.

XRD mineralogy

X-ray diffraction studies of the lateritic regolith samples indicate the presence of serpentine, smectite, kaolinite and illite associated with goethite, hematite, pyrite, calcite, aragonite, olivine and pyroxene (Fig. 7, Table 1). Smectite has sharp basal d_{001} reflections at 15.1–15.7 Å and 14.74 Å diagnostic of high crystallinity, the second reflection has high intensity but a rather broad profile (Fig. 7). These reflections expanded to 16.7–17.2 Å as expected after ethylene-glycol treatment (Fig. 7). The basal spacing of both 15.1–15.7 Å and 14.74 Å is expected when the interlayer cation of the smectite is predominantly calcium. The d_{060} spacing value of smectite is 1.50 Å, indicating a dioctahedral character (Moore and Reynolds, 1989). Rarely the basal spacings of smectite show broad basal reflection and poorly crystallinity and may have formed under extensive lateritic weathering (Fig. 7). Kaolinite was identified from reflections at 7.15 and 3.57 Å reflections. Chrysotile type serpentine was recognized representative sharp reflections at 7.30, 3.65 and 2.51 Å. Kerolite was identified from reflections at 9.5 Å and hydrotalcite at 7.86 Å. Takovite was identified from 7.50 and 3.77 Å reflections.

SEM and STEM-EDS mineralogy

SEM and STEM determinations reveal that smectite, kaolinite and Fe oxide are the main alteration products of ultramafic rocks (Fig. 8). Flaky smectite developed in dissolution voids via the circulation of meteoric water in the saprock units (Fig. 8a). Vermicular crystals resembling brindleyite and irregular grains of pecoraite also are developed in dissolution voids of gypsum, but brindleyite was not identified by XRD, probably due to its low concentrations (Fig. 8b,c). Sub-rounded structures resembling Fe oxide such as goethite developed on microfracture surfaces within ultramafic

rocks (Fig. 8d). Locally, gypsum is associated with altered pyrite developed in calcite + siderite in the sulfide-bearing zone (Fig. 8e). Asbolane exhibits a radial platy form (Fig. 8f). Locally, sparitic calcite crystals developed as meniscus cement in the microfractures of micritic to microsparitic calcite (Fig. 8g). Iron oxide phases such as goethite are associated with aggregates of euhedral quartz crystals (Fig. 8h).

Smectite flakes vary in size from 2 to 15 microns (Fig. 9). X-ray spectra obtained from smectite flakes show dense coatings of Fe oxide (Fig. 9a,b) with appreciable amounts of Fe, Ni, Cr and Mg (Fig. 9c,d). Concentrations of Fe and Ni increase with the thickness of coatings (Fig. 9d). Kaolinite occurs as pseudo-hexagonal platelets with sizes of 2–4 microns (Fig. 9e). X-ray spectra obtained from these pseudo-hexagonal crystal indicate higher Al and similar Si abundances compared to smectite compositions (Fig. 9f). Traces of Cr, Fe and Ni were also detected (Fig. 9f). Takovite ranges from 0.5–1.5 microns in size and X-ray spectra indicates concentrations of around 37 wt.% Ni (Fig. 9g,h).

Bulk chemistry

Chemical analyses of the Çaldağ samples are given in Tables 2 and 3. The samples show variable amounts of Al_2O_3 (0.07–15.51 wt.%), Fe_2O_3 (3.65–79.08 wt.%), SiO_2 (5.07–76.82 wt.%), CaO (0.31–39.83 wt.%), MnO (0.04–0.88 wt.%), Cr_2O_3 (0.01–3.84 wt.%), and loss of ignition (LOI) (4.03–30.18 wt.%). These variations are related to the degree of weathering of the ultramafic rocks. Fe_2O_3 and $\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{MgO} + \text{LOI}$ are high in the ferruginous saprolite, ferricrete and saprolite zones samples, related to an increase in the concentration of goethite±hematite and smectite±serpentine, respectively. The abundances of Fe_2O_3 , SiO_2 and Ni+Co increase in the middle of the lateritic regolith and upward through the profiles parallel

with increased intensity of weathering. In contrast MgO increases up to 14–43 wt.% at the saprock towards the bottommost alteration horizons probably reflect serpentine weathering in saprolite (Table 2; Fig. 5). Additionally Al_2O_3 , Fe_2O_3 and Ni increase in the basic volcanic unit. TOT/S (4.38 wt.%) values is high in the gypsum and pyrite abundant sulfide-bearing zone. There is certainly a correlation between Ni+Co and Mn, and possibly Cr_2O_3 (Fig. 10a,b; Barros de Oliveira et al. 1992; Mano et al. 2014; Kadir et al. 2015). SiO_2 shows a poor positive correlation with Ni+Co (Fig. 10c). Ni exhibits a positive correlation with Co (Fig. 10d). The Nickel (29425 ppm) and Co (1523 ppm) contents are elevated in the claystone zone abundant with smectite and Ni-rich silicates such as pecoraite and brindleyite. Additionally, Ni (4155 ppm) and Co (278 ppm) values are low in the saprock zone composed of mainly serpentine and small amount of smectite, kaolinite and goethite (Tables 1, 3). The Fe-rich and carbonate+gypsum-rich zones associated with average Ni (9346 ppm), (4809) and Co (840 ppm), (269 ppm) concentrations, respectively. Furthermore, 70–85 wt.% of Fe_2O_3 -rich in ferruginous saprolite and ferricrete is associated with 5–3805 ppm Ni, 0.29–0.76 wt.% Cr_2O_3 , and 5–149 ppm Co. SiO_2 increases up to 97.9 wt.% (avg. 76.82 wt.%) in the silcrete at the uppermost associated with avg. 9.50 wt.% CaO and 9.22 wt.% LOI, reflect presence of minor calcite (Table 3; Fig. 5).

Mineral chemistry

The average structural formulae of serpentine, smectite and berthierine were calculated from the chemical analyses of clay fractions (Table 4). The tetrahedral sites are occupied by Si, which is substituted by traces of Al, and traces of Fe in serpentine and smectite, and only Al in berthierine. Magnesium is the dominant cation in the octahedral sites of serpentine and smectite and is accompanied by Fe,

Cr, Ni, Co and Ti, in addition to Al in smectite and berthierine (Kadir et al. 2015). Calcium, Na and K are deemed to be exchangeable interlayer cations. Nickel, Co and Cr show positive correlations with the concentration of Fe in serpentine, smectite and berthierine. The smectite rich clay samples are composed of 33.53–41.01 wt.% SiO₂, Al₂O₃+Fe₂O₃ (13.72–20.64 wt.% and 6.49–8.74 wt.%, respectively), 1.84–8.74 wt.% MgO, and 19–27.1 wt.% LOI suggesting montmorillonite, as reported by Güven (1988) and Newman and Brown (1987). This implication was also supported by the dioctahedral character of smectite based d_{060} reflection values. The high concentration of Fe and low Al values in the octahedral site of sample GB-9A resemble berthierine.

Discussion

Mineralogy and geochemistry

The Çaldağ Ni-Co deposit developed by weathering of serpentinized ultramafic rocks during and following the thrusting of the ophiolitic complex over the metamorphic rocks. The associated normal faulting in the area, which occurred as step structures and complex zonation structure has controlled the present shape of the Ni deposit. Most of the Çaldağ lateritic regolith is composed of ferruginous saprolite, ferricrete, saprolite which is in direct contact with the saprock beneath. The constituent minerals within the ferruginous saprolite and ferricrete zones vary little between lateritic regolith profiles. The development of vertical mineralogical and geochemical zonation, such as an upward increase of smectite ± kaolinite and goethite/hematite + pyrite + gypsum + calcite, and quartz/opal-CT, compared to the decrease in serpentine and altered olivine and pyroxene, indicates the role of

chemical weathering in lateritic regolith formation (Figs. 4, 5; Tables 1, 2; Nahon et al. 1982; Schwertmann 1993; Brand et al. 1998; Kämpf et al. 2000; Freyssinet et al. 2005; Butt and Cluzel 2013; Meunier 2005). The localized association of gypsum and pyrite with calcite in the carbonate- and sulfide-bearing zone probably originated from the overlying sediments. Field observations, textural and micromorphological studies suggest that the formation of goethite was related to chemical weathering and introduction of meteoric water similar to those of the studies by Nagasawa (1978) and Inoue (1995).

Petrographical studies show that olivine and pyroxene were serpentinized due to both uplift and lateritic weathering and subsequent weathering/diagenesis of the ophiolitic complex and that Fe oxide, silica phases, gypsum, pyrite and quartz developed (Schwertmann and Murad 1983; Schwertmann and Taylor 1989; Eren and Kadir 1999; Arslan et al. 2006; Kadir and Akbulut 2009). The physical and chemical weathering of Ni-bearing olivine and pyroxene and the leaching of Mg and Si, and enhancement of Fe resulted in the formation of goethite/hematite and smectite under open and impeded drainage leaching, respectively and influence of intense humid tropical condition (Venturelli et al. 1997; Brand et al. 1998; Freyssinet et al. 2005; Butt and Cluzel 2013; Domènech et al., 2017). Riffel et al. (2016) also reported that weathering of olivine and pyroxenes in basalt from Paraná (Brazil) resulted enrichment of insoluble Al, Fe and Ti, and concentration of Fe favoured precipitation of goethite under permeable organic rich acidic environment. The uplift of the Çaldağ, fluctuation of the semi-arid climatic conditions, and intense physical and chemical weathering and consequence leaching and accumulation of Ni+Co and associated Fe in deeper zone of the lateritic regolith deposits (Freyssinet et al. 2005; Butt and Cluzel 2013).

The high values of LOI and accompanying CaO+TOT/C are important indicators for the abundance of clay and carbonate, respectively, in the lateritic regolith (Christidis and Mitsis 2006; Kadir et al. 2015). Smectite formation requires mild leaching conditions. Oxide zones overly a saprolite zone in all pits (Külah et al. 2014; Kadir et al. 2015; Ekinçi Şans et al. 2015). The positive correlations between Ni+Co and Mn and Cr₂O₃, and relative increases in their abundances with increasing proportion of Fe oxide, Fe-rich smectite and Mn oxide phases in the samples reveal that both Ni and Co are bound within the structures of these minerals (Bocquer et al. 2006; Dublet et al. 2015). The association of Ni and Co with Mn oxide phases was also reported by Butt and Cluzel (2013). Additionally, low values of Ni (9346 ppm) and Co (278 ppm) in the saprock may suggest the association of both elements with Mg, Fe and trace of Mn in the octahedral site of serpentine, smectite, chlorite, kaolinite and goethite.

Heterogeneous concentrations of Ni with goethite and hematite could be controlled by either substitution of Fe³⁺ by Ni²⁺ due to similar ionic radii and charges or sorption of Ni on the surfaces of Fe oxide phases such as goethite (Domènech et al., 2017). This process was controlled by the aging of the chemical weathering and pH 7–6 basic conditions (Dublet et al. 2015). In contrast, the increasing of Ni concentrations toward saprolite and peridotite and decreasing of Ni upward through the saprolite was reported by Gallardo et al. (2010) and Marsh et al. (2010). The concentration of Ni within the smectite, kaolinite, serpentine, and Fe oxide zone phases may be controlled by the concentration of Fe, Al, Mg and the pH of micro-environmental conditions (Christidis and Mitsis, 2006). A much stronger relationship is seen between Ni+Co and Mn, and suggests that intimately mixed clays and Fe oxide can account for the purported incorporation of Ni and Co within Mn oxide

phases and Mn within octahedral sites of clays. Association of Mn with Ni+Co, and precipitation Mn oxides as coating, veins and impregnation in clays was also reported by Butt (1979), Butt and Nickel (1981), Brand et al. (1998) and Domènech et al. (2017). However, Eliopoulos et al. (2012) emphasized the presence of Mn, Co, and Ni in saprolite of Bitincka (Albania) and Gördes (Turkey) is hosted by chromite and (Mn, Co, Ni) oxide phases related to substitution of Mg and Fe by Mn in chromite after transportation and redeposition of the weathered ultramafic units rather than in residual weathering of the ultramafic bedrocks.

The high values of Ni (1000–105000 ppm) and Co (23–5200 ppm) accompanied by relatively low Fe₂O₃ (7–30 wt.%) in the saprolite zone compared to Ni (5–15000 ppm) and Co (5–1410 ppm) in the Fe oxide zone (70–85 wt.% Fe₂O₃) and Ni (3333–16298 ppm) and Co (136–1315 ppm) in the Fe-Ni-bearing zone (30–69 wt.% Fe₂O₃) (Table 2) suggest that Ni+Co are mainly bound within the octahedral site of smectite, serpentine and berthierine, based on calculations of structural formulae, and microchemical EDS analyses of goethite, asbolane, takovite, pecoraite and kaolinite. Similar accompanying of Ni+Co+Cr by Fe and Mg in octahedral site of Fe montmorillonite, nontronite, serpentine, Fe-bearing kaolinite crystals and Fe oxide phases in lateritic regolith of Muratdağ (western Anatolia) was also reported by Kadir et al. (2015). Christidis and Mitsis (2006) also reported occurrence of negative correlation between Ni and Mg and occupying of Mg and Ni±Co in octahedral site of stevensite via substitution of Ni and Co by Mg in the ophiolite complex of Othrys (central Greece). EDS analyses also show 37 wt.% Ni bound to the structure of takovite within the saprolite zone. The Fe and Mg (with related Ni and Co) required for the formation of smectite, serpentine and Fe-Mg-Ni-Co-bearing silicate were produced from chemical weathering of Ni-Co-bearing olivine and pyroxene in the

ultramafic bedrocks, and Al was derived from the volcanic rocks. The depletion of silica during the lateritization processes under relatively poor drainage restrictly leaching resulted in the formation of a silcrete zone in the uppermost part of the deposit (Herdianita et al. 2000; Meunier and Velde 2004; Ece et al. 2013).

Genetic model

Field observations, mineralogical, micromorphological and geochemical analyses reveal that the Çaldağ lateritic regolith deposit developed under the following phases (Fig. 11a–f): Early Paleocene: ophiolite obduction over the Bornova Flysch Zone (Fig. 11a). Paleocene–Eocene: lateritic regolith formation and compressional tectonics resulted in the formation of goethite/hematite, Ni-Co asbolane, Mn oxides, Ni-rich goethite, Ni-rich smectite having colloform structure (residual lateritic regolith) (Fig. 11b). Late Eocene: lateritic regolith formation and compressional tectonics (regional overthrusting of the ophiolitic complex over the metamorphic basement units during the Upper Eocene) (Fig. 11c). Oligo-Miocene–Early Pliocene: lateritic regolith formation, extensional tectonics and lacustrine basin formation (transported weathering of saprock and associated with ferricrete in the Çaldağ area was covered by Mio-Pliocene terrestrial lacustrine sediments) (Fig. 11d). During this lateritic weathering goethite/hematite, Ni-Co-asbolane, takovite, pecoraite, Mn oxides, gypsum, pyrite, Ni-rich clays having colloform and breccia structures, and development of Ni-bearing fractures formed (Freyssinet et al. 2005; Gallardo et al. 2010; Fan and Gerson 2011). Eliopoulos et al. (2012) reported that the wide range of arsenic values (0.004–1.07 wt%) in Gördes lateritic regolith and enhance in ferruginous saprolite may suggest enrichment of arsenic after transportation and redeposition. Latest Early Pliocene–Quaternary: extensional basin formation and

erosion (the Çaldağ horst was uplifted during this stage and Plio-Quaternary alluvial fans formed around the Çaldağ horst due to erosion of the rising blocks) (Fig. 11e; Şengör and Yılmaz 1981; Yılmaz et al. 2000; Ersoy et al. 2014; Külah et al. 2014). Latest Early Pliocene–Quaternary: extensional basin formation and erosion (the latest event resulted in erosion of the cover series and the Çaldağ lateritic deposit cropped out over the Çaldağ area) (Fig. 11f, Kaya et al. 2004; Bozkurt and Sözbilir 2004; Çiftçi and Bozkurt, 2009, 2010).

Conclusions

Lateritic regolith of the Çaldağ residual Ni deposit is formed by the intense tropical chemical weathering of ultramafic rocks under tectonic and high topographic controlled system. The deposit developed by weathering of saprocks during and preceeding the thrusting of the ophiolitic complex over the metamorphic rocks. It formed under two different periods; residual lateritic regolith consisting of oxides formed during the Late Paleocene – Middle Eocene period and a transported ferricrete developed during the Oligocene period. The uplift of the Çaldağ during the Miocene – Pliocene period resulted in weathering and the precipitation of Plio–Quaternary lacustrine and fluvial sediments. The latter are associated with normal faulting in the area, which occurred as step structures and a complex zonation structure that has controlled the present shape of the Ni deposit.

In the deposit, Ni+Co show positive correlation with Fe and Mn occurs in the structures of smectite, berthierine, kaolinite, serpentine, goethite, pecoraite, asbolane, brindleyite and takovite. Petrographically and micromorphologically, the presence of secondary calcite, gypsum, goethite, hematite and pyrite in association

with the lateritic regolith indicates the influence of chemical weathering processes. Both gypsum and calcite were probably formed as secondary evaporative minerals.

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Table Captions

Table 1. Mineralogical variation through the profiles of lateritic regolith.

Ol: olivine, Px: pyroxene, Srp: serpentine, Sme: smectite, Kln: kaolinite, Gth: goethite, Opl: opal-CT, Qz: quartz, Cal: calcite, acc: accessory, +: relative abundance of mineral (abbreviations used after Whitney and Evans, 2010).

843 Table 2. Range of Ni-Co and major oxide values in lateritic regolith.

844 Table 3. Average of major- (wt.%) and trace-element (ppm) compositions of volcanic,

845 saprock and saprolite samples of the study area. Assay values for S would

846 have assisted and supported the presence of sulphides (pyrite) and sulphates

847 (gypsum).

848 Table 4. Chemical compositions (wt.%) and structural formulae for serpentine,

849 smectite, and berthierine samples.

850

Draft

Fig. 1. Location and geological map of the Çaldag lateritic regolith deposit and surrounding area (modified from Karamandereci 1972 and Helvacı et al. 2013).

229x286mm (300 x 300 DPI)

Fig. 2. Detail geological map of the Çaldağ lateritic regolith deposit and surrounding area (modified from Helvacı et al. 2013).

225x316mm (300 x 300 DPI)

Fig. 3. Simplified general stratigraphic section of the study area (modified from Helvacı et al. 2013).

170x221mm (600 x 600 DPI)

Fig. 4. Field photographs: (a-f) General view of the lateritic regolith of the Doktor, North, and South Pits; (g) Relationship between saprock and ferricrete from the North Pit; (h) Overthrust of residual saprolite on transported ferricrete from the Doktor Pit; (i) Saprock; (j) Corrugated garnierite layer between ferruginous saprolite and saprolite zones; (k) Close-up view of j; (l) View of Mn-bearing ferruginous saprolite and garnierite from South Pit; (m) Ni-bearing saprolite; (n) View of botryoidal goethite associated with takovite, gypsum and calcite from South Pit.

248x388mm (300 x 300 DPI)

Fig. 4 (continued)

235x349mm (300 x 300 DPI)

Fig. 5. Schematic lateritic regolith profile of the study area.

91x48mm (600 x 600 DPI)

Fig. 6. Photomicrographs showing: (a) Chromite crystals in serpentinized dunitic ultramafic rocks; (b) Serpentinized pyroxene in ultramafic rocks which is partly chloritized. Bedrocks occurring towards the base; (c,d) Serpentine and Fe oxide infills in fractures of lateritized zone. Ol: Olivine, Px: Pyroxene, Chr: Chromite, Chl: Chloritization, Srp: Serpentine, Fe: Fe oxide.

117x88mm (300 x 300 DPI)

Fig. 7. X-ray diffraction patterns for clay fraction samples. Ol: Olivine, Px: Pyroxene, Srp: Serpentine, Sme: Smectite, Kln: Kaolinite, Ilt: Illite, Tkv: Takovite, Krt: Kerolite, Htlc: Hydrotalcite, Gth: Goethite, Hmt: Hematite, Py: Pyrite, Op: Opal-CT, Qz: Quartz, Cal: Calcite, Arg: Aragonite (abbreviations used after Whitney and Evans 2010).

268x422mm (300 x 300 DPI)

Fig. 8. SEM images of: (a) Flaky smectite on and between relict olivine and pyroxene; (b) Vermiform brindleyite developed within a microfracture of gypsum; (c) Pecoraite associated with gypsum; (d) Association of nodular gypsum with goethite; (e) Association of gypsum with pyrite, siderite and calcite; (f) Radial platy form of asbolane; (g) Development of sparitic calcite in microfracture of micritic and microsparitic calcite; (h) Association of euhedral quartz aggregates with goethite. Sme: Smectite, Qz: Quartz, Brt: Brindleyite, Gp: Gypsum, Pc: Pecoraite, Gth: Goethite, Py: Pyrite, Cal: Calcite, Sd: Siderite, Asb: Asbolane (abbreviations used after Whitney and Evans 2010).

191x289mm (300 x 300 DPI)

Fig. 9. Bright field TEM images and EDS spectra of: (a-b) Smectite flake with various light and dense coatings; (c-d) Fe, Ni, Cr, and Mg in smectite flake; (e) Kaolinite crystal in micron size; (f) Strong Al- and Si-spectra and traces of Cr, Fe in kaolinite; (g) Takovites crystal in micron size; (h) High concentration of Ni in takovites particles. Sme: Smectite, Kln: Kaolinite, Tkv: Takovite (abbreviations used after Whitney and Evans 2010).

216x364mm (600 x 600 DPI)

Fig. 10. Elemental variation diagrams for major oxides (wt.%) and trace elements (ppm) of the Çaldağ samples. (a) MnO vs. Ni+Co; (b) Cr₂O₃ vs. Ni+Co; (c) SiO₂ vs. MgO+Al₂O₃+Fe₂O₃; (d) Ni vs. Co.

160x127mm (600 x 600 DPI)

Fig. 11. Genetic model of the Çaldağ lateritic regolith deposit: (a) Early Paleocene: ophiolite obduction over the Bornova Flysch Zone; (b) Paleocene–Eocene: residual lateritic regolith formation and compressional tectonics; (c) Late Eocene: lateritic regolith formation overthrusting of the ophiolitic complex over the Bornova Flysch Zone; (d) Oligo-Miocene–Early Pliocene: transported lateritic regolith formation, extensional tectonics and lacustrine basin formation over the Menderes Massif; (e) Latest Early Pliocene–Quaternary: extensional basin formation, uplift and erosion of the Çaldağ deposit; (f) Latest Early Pliocene–Quaternary: extensional basin formation and erosion of the cover series and exposure of the Çaldağ lateritic regolith deposit.

194x218mm (600 x 600 DPI)

Rock type	Ol	Px	Srp	Sme	Kln	Gth	Opl	Qz	Cal	Jr
Fe-bearing silcrete				++		+	+++	acc		
Fe-bearing silcrete				++		+	++	acc		
Ferruginous saprolite						+++++				
Ferruginous saprolite						+++			+	+
Fault related saprolite			++	++		acc		+		
Saprolite	+	+		+++						
Serpentinized ultramafic rocks					+	acc	++			
(saprock)				+						
Serpentinized ultramafic rocks										
(saprock)			+++++							
Ultramafic bedrocks	++++	+								

Table 1

Rock type	SiO ₂ (wt.%)	Al ₂ O ₃ (wt.%)	Fe ₂ O ₃ (wt.%)	MgO (wt.%)	CaO (wt.%)	MnO (wt.%)	Ni (ppm)	Co (ppm)
Basic volcanics	32-57	10-23	2-22	1-7	0-13	0-0.2	5-10000	34-528
Silcrete	40-95	0-6	0-40	0.5-1	0-15	0-0.05	11-10000	60-2444
Ferruginous saprolite	2-15	0-2	70-85	0-1	0-2	0-2	5-15000	5-1410
Ni-bearing ferruginous saprolite	20-56	1-10	30-69	0-2	0-2	0-1	3333-16298	136-1315
Carbonate-, gypsum-bearing zone	0-40	0-1	1-11	0-5	15-52	0-0.7	181-23000	9-1463
Ni-rich saprolite	9-64	9-20	7-30	1-9	0-5	0-3	1000-105000	23-5200
Serpentinized ultramafic rocks (saprock)	16-45	0,1-1	7-23	14-43	0-33	0-0.3	1482-11000	40-620

Table 2

Major oxides (wt.%)	Volcanics Avg. (n=19)	Serpentinized Ultramafic rocks (Saprocks) Avg. (n=7)	Saprolite Avg. (n=8)	Carbonate-, gypsum-bearing zone Avg. (n=11)	Ferruginous saprolite Avg. (n=5)	Ni-bearing Ferruginous saprolite Avg. (n=6)	Silcrete Avg. (n=5)
SiO ₂	50.07	34.43	32.07	10.46	5.07	35.94	76.82
Al ₂ O ₃	15.51	3.47	13.56	0.40	1.28	1.67	0.07
ΣFe ₂ O ₃	10.68	9.43	13.12	7.53	79.08	43.05	3.65
MgO	4.98	24.61	2.96	0.48	0.39	0.90	0.40
CaO	8.39	8.56	4.02	39.83	0.57	0.31	9.50
Na ₂ O	4.50	0.06	0.089	0.01	0.04	0.03	0.01
K ₂ O	0.19	0.04	0.06	0.04	0.04	0.07	0.04
TiO ₂	1.36	0.32	1.99	0.01	0.06	0.02	0.01
P ₂ O ₅	0.11	0.09	0.03	0.01	0.02	0.03	0.03
MnO	0.14	0.13	0.88	0.29	0.07	0.61	0.04
Cr ₂ O ₃	0.01	2.99	3.84	0.53	2.562	1.26	0.18
LOI	4.03	15.29	23.39	30.18	12.64	14.73	9.22
Total	100.00	99.98	99.72	90.33	100.13	99.80	99.99
TOT/C	0.09	1.38	0.84	6.71	0.192	0.13	2.10
TOT/S	0.04	0.02	0.046	4.38	0.07	0.02	0.02
Trace elements (ppm)							
Ba	53	57	177	32	39	318	20
Be	b.d.l.	b.d.l.	3.4	b.d.l.	1	2.5	b.d.l.
Co	55	279	1523	269	48	840	91
Cs	2	b.d.l.	2	b.d.l.	b.d.l.	4	b.d.l.
Ga	18	b.d.l.	6	b.d.l.	4	3	b.d.l.
Hf	3	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	2	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	42	4155	29425	4809	1699	9346	584
Rb	3	b.d.l.	b.d.l.	b.d.l.	b.d.l.	4	b.d.l.
Sc	32	12	126	14	12	40	1.8
Sr	b.d.l.	b.d.l.	33	63	9	16	b.d.l.
Ta	178	24	b.d.l.	b.d.l.	b.d.l.	b.d.l.	12
Th	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
U	b.d.l.	b.d.l.	47	13	9	8	b.d.l.
V	b.d.l.	b.d.l.	216	25	161	102	1
W	325	54	34	15	7	b.d.l.	b.d.l.
Zr	171	15	150	2	6	b.d.l.	570
Y	80	b.d.l.	3	2	2	6	b.d.l.
La	33	b.d.l.	b.d.l.	b.d.l.	1	6	b.d.l.
Ce	5	8	b.d.l.	b.d.l.	b.d.l.	8	b.d.l.
Pr	12	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.
Nd	2	2	b.d.l.	b.d.l.	b.d.l.	5	b.d.l.
Sm	10	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.
Eu	3	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Gd	5	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.
Tb	5	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Dy	1	b.d.l.	1	b.d.l.	b.d.l.	1	b.d.l.
Ho	5	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Er	1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.
Tm	4	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Yb	1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.
Lu	4	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Cu	1	b.d.l.	41	26	40	41	b.d.l.

b.d.l.: below detection limit.

Table 3

Major oxides (wt.%)	Serpentine			Smectite			Berthierine		
	DD-3	D-10	Avg.	D-15	D-16	GB-5A	GB-5B	Avg.	GB-9A
SiO ₂	38.59	39.00	38.80	37.81	41.01	35.75	33.53	38.81	20.50
Al ₂ O ₃	0.98	0.23	0.61	20.64	13.72	17.22	13.93	13.35	14.24
ΣFe ₂ O ₃	9.57	19.28	14.43	6.49	7.23	8.74	7.58	9.56	29.58
MgO	43.33	28.03	35.68	3.08	1.82	2.19	4.76	4.12	1.45
CaO	0.09	0.02	0.06	0.39	0.50	0.61	0.61	0.61	0.47
Na ₂ O	0.01	0.02	0.02	0.07	0.05	0.11	0.08	0.06	0.35
K ₂ O	0.04	0.04	0.04	0.04	0.05	0.16	0.04	0.07	0.04
TiO ₂	0.01	0.01	0.01	0.07	0.02	15.26	0.12	3.10	0.01
MnO	0.12	0.23	0.18	0.07	0.05	0.01	0.27	0.16	3.36
Cr ₂ O ₃	0.46	0.30	0.38	3.20	7.29	0.22	17.18	5.70	1.08
NiO	0.29	1.14	0.72	1.48	0.88	0.30	0.52	1.77	3.07
CoO	0.01	0.04	0.03	0.02	0.01	0.002	0.04	0.03	0.52
LOI	6.5	12	9.25	26.2	27.1	19	21.1	22.08	24.2
Total	100	100	100	99.56	99.73	99.57	99.76	99.41	98.87
SiO ₂ /Al ₂ O ₃	39.38	170	105	1.83	2.99	2.08	2.41	9.15	1.44
SiO ₂ /R ₂ O ₃	3.66	2.00	2.83	1.39	1.96	1.38	1.56	1.74	0.03
CIA	88	74	81	98	96	95	95	88	94
Tetrahedral									
Si	3.46	3.76	3.61	6.50	7.53	5.64	6.72	6.71	2.53
Al	0.10	0.03	0.07	1.50	0.47	2.36	1.28	1.17	1.47
Fe	0.44	0.21	0.33	0.00	0.00	0.00	0.00	0.12	0.00
Σ	4.00	4.00	4.00	8.00	8.00	8.00	8.00	8.00	4.00
Octahedral									
Al	0.00	0.00	0.00	2.69	2.51	0.84	2.01	1.61	0.60
Fe	0.21	1.19	0.70	0.84	1.00	1.04	1.14	1.10	2.75
Mg	5.80	4.02	4.91	0.79	0.50	0.51	1.42	1.05	0.27
Ti	0.001	0.001	0.00	0.01	0.003	1.81	0.02	0.37	0.001
Mn	0.01	0.02	0.02	0.01	0.01	0.002	0.06	0.03	0.45
Cr	0.05	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.06	0.24	0.15	0.55	0.35	0.10	0.22	0.62	0.81
Co	0.001	0.004	0.00	0.004	0.002	0.0003	0.008	0.00	0.065
Σ	6.13	5.51	5.82	4.89	4.36	4.30	4.90	4.79	4.95
Interlayer									
Ca	0.01	0.002	0.01	0.07	0.10	0.10	0.13	0.11	0.06
Na	0.002	0.004	0.00	0.02	0.02	0.03	0.03	0.02	0.08
K	0.01	0.005	0.01	0.01	0.01	0.03	0.01	0.01	0.01
Σ	0.02	0.01	0.02	0.10	0.13	0.17	0.17	0.15	0.15
Tetrahedral charge	-0.47	-0.74	-0.61	0.50	0.47	0.36	1.28	0.69	1.47
Octahedral charge	0.49	0.75	0.62	-0.32	-0.24	-0.09	-0.97	-0.42	-1.25
Total charge	0.02	0.01	0.02	0.18	0.23	0.27	0.30	0.26	0.21
Interlayer charge	0.02	0.01	0.03	0.18	0.23	0.27	0.30	0.26	0.21

CIA: Chemical index of alteration.

Table 4

Major oxides (wt.%)	Volcanics									
	CD-1	CD-2	RECD-2	CD-3	CD-4	CD-5	CD-6	CD-7	CD-8	CD-9
SiO ₂	49.66	47.51	48.1	52.99	50.48	51.98	51.80	52.21	49.37	57.37
Al ₂ O ₃	17.90	16.67	16.26	15.20	17.05	16.24	14.15	15.99	17.17	13.31
ΣFe ₂ O ₃	9.59	12.37	12.72	12.06	11.36	11.31	13.1	11.64	10.84	9.11
MgO	3.53	3.90	3.86	3.98	3.55	3.53	4.34	3.55	3.83	2.75
CaO	8.15	8.60	8.46	5.61	6.02	5.69	5.85	4.81	7.62	9.96
Na ₂ O	5.06	4.42	4.29	5.01	5.69	6.10	5.08	6.44	5.10	2.40
K ₂ O	0.19	0.04	0.04	0.32	0.30	0.08	0.13	0.15	0.12	0.14
TiO ₂	1.31	1.69	1.72	1.73	1.59	1.60	2.04	1.85	1.47	0.65
P ₂ O ₅	0.11	0.12	0.12	0.14	0.12	0.15	0.16	0.20	0.12	0.11
MnO	0.12	0.15	0.15	0.15	0.13	0.13	0.16	0.15	0.16	0.10
Cr ₂ O ₃	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.010
LOI	4.4	4.4	4.3	2.8	3.7	3.2	3.2	3	4.2	4.1
Total	100.03	99.88	100.03	99.99	100.00	100.02	100.02	99.99	100.02	100.01
TOT/C	0.02	0.03	0.03	0.04	0.02	0.03	0.05	0.04	0.05	0.06
TOT/S	0.01	0.04	0.01	0.15	0.03	0.01	0.01	0.01	0.02	0.01
Trace elements (ppm)										
Ba	53.5	41	43.7	110.4	55.7	32.8	47	45.6	49.2	42.1
Be	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Co	34	46.1	48.6	72.1	47.9	56.1	52.9	70.7	52.2	68.5
Cs	b.d.l.	b.d.l.	b.d.l.	0.1	0.1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ga	20.3	20.3	20.8	17.4	17.1	16.8	21.5	18.7	18.4	21.9
Hf	2.3	2.8	2.6	3.2	3.0	3.3	3.2	4.1	2.4	2.3
Nb	1	1.1	1.1	1.3	1.2	1.3	1.5	1.6	1.1	2.9
Ni	17	12	17	5	8	12	5	5	22	65
Rb	2.4	b.d.l.	b.d.l.	3.2	3.0	0.7	1.2	1.7	1.5	3.2
Sc	24	33	33	31	29	28	34	30	30	26
Sn	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.	1	b.d.l.	b.d.l.	1
Sr	158.8	56.3	56.9	269.6	267.5	83	151	142.4	80.8	123.1
Ta	b.d.l.	0.1	b.d.l.	0.1	b.d.l.	0.1	0.1	b.d.l.	b.d.l.	0.3
Th	0.3	0.1	0.2	0.5	0.3	0.4	0.3	0.4	0.3	1.5
U	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	b.d.l.	0.6
V	335	482	498	359	415	366	446	278	349	190
W	59.9	98	110.9	388.3	134.3	225.4	179.5	358.4	163.1	427.2
Zr	72.3	78.7	82	100.6	85.7	97.8	105	129	86.1	66.8
Y	30.1	33.5	33.6	40.7	35.2	40.9	45.8	49	38.6	29.6
La	3.3	5.3	3.3	6.0	3.8	4.1	4.8	5	3.5	13.3
Ce	10	10.4	10.1	13.7	10.4	12	14.3	13.8	10.7	19.1
Pr	1.62	1.77	1.74	2.20	1.81	2.05	2.47	2.50	1.77	3.48
Nd	8.8	9.6	10.5	12.1	8.8	10.7	12.4	13	9.4	14.8
Sm	3.2	3.5	3.4	3.9	3.4	3.8	4.2	5.1	3.5	3.8
Eu	1.29	1.39	1.31	1.59	1.33	1.44	1.76	1.87	1.36	1.25
Gd	4.28	4.47	4.51	5.66	4.60	5.36	6.16	6.67	4.88	4.28
Tb	0.76	0.88	0.91	1.17	0.92	1.12	1.19	1.30	0.99	0.84
Dy	4.47	5.03	5.11	6.38	5.60	6.29	7.37	8.31	6.11	4.98
Ho	1.09	1.32	1.30	1.49	1.25	1.51	1.79	1.90	1.39	1.11
Er	3.16	3.55	3.49	4.15	3.61	4.33	4.60	5.13	4.12	3.16
Tm	0.49	0.53	0.56	0.68	0.56	0.70	0.74	0.79	0.68	0.51
Yb	3.01	3.31	3.42	4.14	3.84	4.32	4.81	5.24	4.06	3.08
Lu	0.45	0.50	0.50	0.63	0.58	0.60	0.68	0.72	0.57	0.44
Cu	30.3	8.2	8.3	22.2	41.1	6.4	5.4	7.9	5.5	46.9

b.d.l.: below detection limit.

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Volcanics (continued)										
Major oxides (wt.%)	CD-10	CD-11	CD-12	CD-13	CD-14	CD-15	CD-16	CD-17	CD-18	Average
SiO ₂	51.39	47.53	48.13	48.35	50.82	49.1	48.87	48.19	47.52	50.07
Al ₂ O ₃	18.65	16.23	13.52	13.87	14.77	14.43	14.36	14.31	14.63	15.51
ΣFe ₂ O ₃	8.13	10.03	11.25	11.47	8.38	11.52	11.56	8.17	8.23	10.68
MgO	4.73	4.72	6.78	6.74	6.85	6.80	6.77	7.65	6.74	4.98
CaO	5.89	11.67	10.35	9.87	9.12	8.89	9.11	10.76	12.96	8.39
Na ₂ O	5.42	3.86	3.81	3.56	4.64	3.66	3.5	4.15	3.26	4.50
K ₂ O	0.5	0.04	0.04	0.2	0.18	0.51	0.54	0.04	0.04	0.19
TiO ₂	1.07	1.17	1.33	1.3	0.95	1.38	1.37	0.86	0.85	1.36
P ₂ O ₅	0.09	0.09	0.13	0.13	0.09	0.13	0.14	0.09	0.09	0.11
MnO	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.13	0.14	0.14
Cr ₂ O ₃	0.003	0.013	0.018	0.018	0.054	0.019	0.018	0.051	0.05	0.01
LOI	4	4.5	4.5	4.2	4	3.4	3.6	5.6	5.5	4.03
Total	100.01	100.01	99.99	99.86	100.01	100.00	100.00	100.02	100.01	100.00
TOT/C	0.04	0.08	0.19	0.14	0.09	0.02	0.03	0.51	0.23	0.09
TOT/S	0.04	0.01	0.01	0.14	0.03	0.06	0.08	0.01	0.01	0.04
Trace elements (ppm)										
Ba	98	42.7	44.2	54.8	39.2	63	70.1	29.6	40.1	53
Be	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.	b.d.l.	b.d.l.
Co	50.3	47.6	59	57	61.1	53.9	58.2	46	56.9	55
Cs	0.5	b.d.l.	1.5	4.3	0.9	8.7	8.8	1.2	0.7	2
Ga	16.1	23	17.2	17.4	12	15.5	16.2	13.8	17.9	18.02
Hf	2	2	2.7	2.5	1.8	2.6	2.6	1.5	1.7	2.6
Nb	0.8	0.8	5.4	5.2	2.2	5.2	5.7	2.5	2.4	2.3
Ni	12	56	61	51	125	59	60	109	94	41.8
Rb	7.1	b.d.l.	0.6	3.5	3.6	7.6	7.9	b.d.l.	b.d.l.	2.62
Sc	19	31	39	38	38	40	40	35	34	32.2
Sn	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Sr	302.5	98.2	190.9	257.5	231.1	351	343.8	147.4	67.7	177.9
Ta	b.d.l.	b.d.l.	0.3	0.4	0.1	0.4	0.3	0.1	0.2	0.17
Th	0.2	0.1	0.6	0.5	0.1	0.5	0.6	0.2	0.5	0.4
U	b.d.l.	0.1	1.1	0.2	b.d.l.	0.1	0.1	0.7	0.5	0.24
V	236	313	296	302	234	312	308	225	229	324.9
W	209.3	101.7	143.2	96.3	140	79	118.2	53.3	152.9	170.5
Zr	63	63.8	83.1	80.7	54.3	86.5	84	50.1	48.3	79.9
Y	23.6	28.3	34.3	33.5	23.3	34.3	33.9	22.8	22.6	33.3
La	2.8	3.3	5.8	6	2.9	5.7	5.6	3.6	3.3	4.81
Ce	7.9	9	14.7	14.9	8	15.1	14.6	9	10	11.98
Pr	1.34	1.51	2.21	2.1	1.25	2.24	2.17	1.31	1.62	1.96
Nd	7.9	7.8	10.8	11.5	6.3	11.4	11.2	6.6	8.8	10.1
Sm	2.4	2.5	3.1	3.2	2.3	3.4	3.2	2	3.2	3.32
Eu	1	1.1	1.32	1.22	0.83	1.33	1.16	0.91	1.29	4.46
Gd	3.19	3.91	4.32	4.41	3.01	4.79	4.74	2.8	4.28	4.54
Tb	0.68	0.78	0.89	0.9	0.68	0.83	0.92	0.6	0.76	0.90
Dy	3.6	4.37	5.5	5.31	3.6	5.33	5.42	3.38	4.47	5.30
Ho	0.95	1.02	1.33	1.17	0.85	1.22	1.25	0.84	1.09	1.26
Er	2.57	2.81	3.81	3.48	2.42	3.65	3.53	2.25	3.16	3.53
Tm	0.41	0.51	0.6	0.54	0.4	0.57	0.58	0.35	0.49	0.56
Yb	2.47	2.85	3.93	3.44	2.47	3.58	3.72	2.39	3.01	3.53
Lu	0.37	0.46	0.57	0.5	0.37	0.53	0.53	0.36	0.45	0.52
Cu	14.5	51.4	55.7	54.3	73.8	66.5	60.9	50.8	72	35.9

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14 Table 3 – cjes-2017-0184suppla (continued 1)

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	Serpentinized ultramafic rocks (saprock)							
Major oxides (wt.%)	DD-1	DD-2	DD-3	D-10	GB-1	K27	D-18	Average
SiO ₂	44.61	44.43	38.59	33.28	36.36	15.99	27.76	34.43
Al ₂ O ₃	1.17	1.06	0.98	0.23	10.3	0.14	10.44	3.47
ΣFe ₂ O ₃	7.55	8.49	9.57	19.28	9.31	4.43	7.38	9.43
MgO	40.03	40.38	43.33	28.03	5.92	14.03	0.55	24.61
CaO	2.10	1.27	0.09	0.02	21.80	33.42	1.19	8.56
Na ₂ O	0.02	0.01	0.01	0.02	0.22	0.01	0.10	0.06
K ₂ O	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
TiO ₂	0.03	0.02	0.01	0.01	2.12	0.01	0.03	0.32
P ₂ O ₅	0.01	0.01	0.01	0.01	0.40	0.01	0.15	0.09
MnO	0.11	0.13	0.12	0.23	0.16	0.04	0.13	0.13
Cr ₂ O ₃	0.415	0.371	0.462	0.297	0.076	0.154	19.164	2.99
LOI	3.7	3.6	6.5	17.1	13.1	31.5	31.5	15.29
Total	100.04	100.06	100.02	99.96	99.98	99.92	99.90	99.98
TOT/C	0.06	0.07	0.11	0.11	1.81	7.12	0.38	1.38
TOT/S	0.02	0.01	0.01	0.02	0.01	0.06	0.01	0.02
Trace elements (ppm)								
Ba	1	1	2.5	137.9	139.8	14.6	102.1	57
Be	b.d.l.	b.d.l.	b.d.l.	b.d.l.	2	b.d.l.	3	b.d.l.
Co	107.2	102.3	128.3	421.8	40.6	41.1	1109.1	279
Cs	b.d.l.	b.d.l.	b.d.l.	0.9	9.2	0.5	1.7	b.d.l.
Ga	1.6	1.2	1.6	0.6	15	b.d.l.	1.6	b.d.l.
Hf	b.d.l.	b.d.l.	b.d.l.	b.d.l.	4.1	b.d.l.	b.d.l.	b.d.l.
Nb	3.3	0.6	b.d.l.	b.d.l.	33.9	b.d.l.	0.6	b.d.l.
Ni	2288	2250	2883	11415	1571	1482	7194	4155
Rb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	6.5	b.d.l.
Sc	13	13	4	5	20	1	28	12
Sn	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1	b.d.l.	b.d.l.	b.d.l.
Sr	2.1	0.7	0.7	7	108	28.7	21.1	24.04
Ta	1.2	0.2	0.1	b.d.l.	2.3	b.d.l.	b.d.l.	b.d.l.
Th	b.d.l.	b.d.l.	b.d.l.	b.d.l.	3.9	b.d.l.	0.5	b.d.l.
U	b.d.l.	b.d.l.	b.d.l.	0.6	1.3	1.1	6.4	b.d.l.
V	58	47	28	22	182	8	32	53.86
W	99.1	0.5	0.2	0.1	3	0.1	0.3	14.76
Zr	b.d.l.	b.d.l.	b.d.l.	2.5	159.5	b.d.l.	3.7	b.d.l.
Y	0.9	0.3	b.d.l.	1.1	22.3	b.d.l.	13.8	b.d.l.
La	1.1	1.1	1.7	1.4	34.9	1.1	15.7	8.14
Ce	b.d.l.	b.d.l.	0.5	0.8	69.6	b.d.l.	3.8	b.d.l.
Pr	0.07	0.05	0.06	0.18	8.02	0.04	4.9	1.90
Nd	b.d.l.	b.d.l.	b.d.l.	0.7	32.1	b.d.l.	23.1	b.d.l.
Sm	b.d.l.	b.d.l.	b.d.l.	0.2	6.2	b.d.l.	5.2	b.d.l.
Eu	b.d.l.	b.d.l.	b.d.l.	b.d.l.	2.04	b.d.l.	1.15	b.d.l.
Gd	0.09	b.d.l.	0.07	0.21	5.45	b.d.l.	4.21	b.d.l.
Tb	0.01	0.01	b.d.l.	0.02	0.85	b.d.l.	0.62	b.d.l.
Dy	0.15	0.06	b.d.l.	0.18	4.07	b.d.l.	3.43	b.d.l.
Ho	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.78	b.d.l.	0.72	b.d.l.
Er	0.13	b.d.l.	b.d.l.	0.12	1.98	b.d.l.	2.14	b.d.l.
Tm	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.28	b.d.l.	0.34	b.d.l.
Yb	0.09	b.d.l.	b.d.l.	0.15	1.61	b.d.l.	2.35	b.d.l.
Lu	0.02	b.d.l.	b.d.l.	0.02	0.22	b.d.l.	0.42	b.d.l.
Cu	41	21.3	1	15.5	81.2	1.8	30.7	27.5

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26 Table 3 – cjes-2017-0184suppla (continued 2)

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	Saprolite								
Major oxides (wt.%)	D-15	D-16	K17	GB-3	GB-5A	GB-5B	GB-9A	GB-12	Average
SiO ₂	37.81	41.01	45.94	33.31	35.75	33.53	20.5	8.73	32.07
Al ₂ O ₃	20.64	13.72	1.26	15.91	17.22	13.93	14.24	11.56	13.56
ΣFe ₂ O ₃	6.49	7.23	17.74	19.22	8.74	7.58	29.58	8.36	13.12
MgO	3.08	1.82	8.74	0.79	2.19	4.76	1.45	0.82	2.96
CaO	0.39	0.5	0.95	4.86	0.61	0.61	0.47	23.74	4.02
Na ₂ O	0.07	0.05	0.01	0.01	0.11	0.08	0.35	0.03	0.089
K ₂ O	0.04	0.05	0.04	0.04	0.16	0.04	0.04	0.04	0.06
TiO ₂	0.07	0.02	0.01	0.38	15.26	0.12	0.01	0.01	1.99
P ₂ O ₅	0.01	0.01	0.01	0.03	0.13	0.01	0.01	0.01	0.03
MnO	0.07	0.05	0.4	1.33	0.01	0.27	3.36	1.53	0.88
Cr ₂ O ₃	3.2	7.287	0.598	1.007	0.221	17.175	1.082	0.135	3.84
LOI	26.2	27.1	17	21.2	19	21.1	24.2	31.3	23.39
Total	99.96	100	99.85	99.6	99.78	99.85	99.18	99.51	99.72
TOT/C	0.11	0.05	0.18	0.99	0.06	0.08	0.11	5.12	0.84
TOT/S	0.01	0.01	0.01	0.01	0.16	0.01	0.01	0.15	0.046
Trace elements (ppm)									
Ba	178.7	21.9	276.2	487.5	263.6	41	40.4	108.7	177
Be	3	1	3	3	4	1	8	4	3.38
Co	146.9	77.2	712.3	2497.6	22.9	381.8	5206.5	3140.6	1523
Cs	1	1.4	2.8	2.8	0.4	1.8	3.4	0.2	2
Ga	3	3.1	1	7.6	20.3	9.7	5.4	1.1	6.4
Hf	b.d.l.	b.d.l.	b.d.l.	0.8	32.2	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	b.d.l.	b.d.l.	b.d.l.	4.6	295.7	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	14832	8774	56589	12034	2946	5208	30675	104341	29424.9
Rb	1.3	2.6	0.8	b.d.l.	0.8	1.3	1.3	b.d.l.	b.d.l.
Sc	81	378	28	168	57	76	156	61	125.63
Sr	20.7	18.3	7.3	17.9	146.1	17.1	18.4	18.9	33.09
Ta	b.d.l.	b.d.l.	b.d.l.	0.4	20.7	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Th	b.d.l.	0.4	b.d.l.	2.5	1.3	b.d.l.	b.d.l.	0.2	b.d.l.
U	19.2	9.8	9.5	27.8	244.8	1.2	6.4	60.6	47.41
V	102	47	40	86	689	657	96	8	215.63
W	0.2	0.2	0.3	5	247.6	12.5	2.9	0.1	33.6
Zr	3.6	b.d.l.	0.5	28.4	1156.3	7.7	0.8	0.9	149.84
Y	1.6	1.2	1.6	5.1	2.8	0.4	6	4.7	2.93
La	2	1.4	1.6	3.3	19.3	b.d.l.	0.6	2.5	b.d.l.
Ce	0.8	2.1	b.d.l.	22.1	16.9	0.9	2.2	5.5	b.d.l.
Pr	0.21	0.3	0.09	0.85	1.01	0.05	0.1	0.79	0.43
Nd	0.7	1.3	b.d.l.	4.2	2.7	b.d.l.	0.6	3.5	b.d.l.
Sm	0.2	0.3	b.d.l.	0.8	0.5	b.d.l.	0.2	0.8	b.d.l.
Eu	b.d.l.	b.d.l.	b.d.l.	0.28	0.16	b.d.l.	0.1	0.28	b.d.l.
Gd	0.19	0.28	0.14	0.82	0.51	0.08	0.44	0.94	0.43
Tb	0.03	0.03	0.02	0.16	0.08	b.d.l.	0.08	0.14	b.d.l.
Dy	0.23	0.26	0.06	0.85	0.53	0.05	0.75	0.86	0.45
Ho	b.d.l.	b.d.l.	b.d.l.	0.17	0.11	b.d.l.	0.19	0.16	b.d.l.
Er	0.14	0.12	0.09	0.5	0.36	b.d.l.	0.66	0.46	b.d.l.
Tm	b.d.l.	b.d.l.	b.d.l.	0.11	0.06	b.d.l.	0.11	0.1	b.d.l.
Yb	0.16	0.15	0.07	0.59	0.44	0.07	0.78	0.43	0.34
Lu	0.02	0.02	0.03	0.09	0.06	0.01	0.13	0.1	0.058
Cu	110	68.3	15.2	56.2	7.7	3.2	61.6	3.1	40.66

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Table 3 – cjes-2017-0184suppla (continued 3)

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Major oxides (wt. %)	Carbonate-, gypsum-bearing zone											Average
	GB-10	As-7	K-12A	K-20	K-21	K-22	K-23	K-24	K-25	K-29	K-30	
SiO ₂	3.03	16.65	0.27	12.78	40.65	27.28	0.48	1.01	11.42	1.31	0.19	10.46
Al ₂ O ₃	1.26	0.03	0.29	0.18	0.5	0.43	0.67	0.26	0.20	0.23	0.33	0.40
ΣFe ₂ O ₃	8.51	3.33	7.76	6.75	11.34	9.11	14.5	1.94	7.57	5.84	6.18	7.53
MgO	0.24	1.49	0.61	0.39	0.44	0.19	0.30	0.27	0.40	0.38	0.53	0.48
CaO	44.92	42.99	46.48	44.5	14.57	19.81	26.75	55.68	43.74	52.07	46.58	39.83
Na ₂ O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
K ₂ O	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
TiO ₂	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
P ₂ O ₅	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MnO	0.64	0.05	0.25	0.31	0.30	0.04	0.01	0.37	0.34	0.71	0.22	0.29
Cr ₂ O ₃	0.635	0.198	0.387	0.311	0.630	0.845	1.569	0.073	0.509	0.193	0.436	0.53
LOI	37.6	35.2	32.4	34.4	12.7	15.6	19.7	39.9	35.4	38.2	30.9	30.18
Total	99.83	100.03	88.71	100.01	82.11	73.49	64.03	99.92	99.98	99.94	85.58	90.33
TOT/C	8.90	8.96	8.72	8.78	0.81	0.14	0.33	9.71	9.07	9.75	8.69	6.71
TOT/S	0.01	0.01	5.93	0.39	7.74	10.78	15.19	0.09	0.09	0.11	7.89	4.38
Trace elements (ppm)												
Ba	26.5	13.4	8.8	27.5	34.4	2.8	2.9	18.1	176.9	39.3	6.2	32
Be	3	b.d.l.	1	1	3	1	b.d.l.	2	2	10	1	b.d.l.
Co	1463.6	72.2	102.5	117.1	194.8	51.6	23.6	151.1	148.3	555.7	82.4	269
Cs	1.1	0.1	0.3	0.3	0.9	1.2	b.d.l.	b.d.l.	0.2	0.2	0.4	b.d.l.
Ga	1.7	b.d.l.	0.8	b.d.l.	0.7	0.8	2.8	b.d.l.	0.6	b.d.l.	0.5	b.d.l.
Hf	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	23422	888	1824	2786	7460	1143	181	3046	2952	7703	1495	4809.1
Rb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.6	0.8	0.7	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Sc	56	1	5	11	18	4	1	13	14	28	5	14.18
Sr	8.9	13.9	121.5	68.9	40.9	60.9	81	63.4	46.5	79.3	103.6	62.62
Ta	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Th	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
U	6.7	0.4	4.4	18.3	19.2	17.7	1.2	13.5	11	48.6	5.8	13.35
V	27	6	19	22	43	32	63	9	18	15	21	25
W	1.1	156	0.6	0.5	0.8	1	2.4	0.4	0.7	0.4	0.8	14.97
Zr	0.5	0.7	1.7	1.9	2.5	1.5	2	1.4	2.6	1.6	1.7	1.65
Y	8.1	0.1	1	2.1	1.7	0.5	0.3	2.8	1.8	6	1	2.31
La	0.6	b.d.l.	1	3.3	1.1	1.7	2.5	4.1	1.2	1.8	2.8	b.d.l.
Ce	b.d.l.	b.d.l.	0.9	0.9	b.d.l.	0.6	0.7	1.2	0.5	0.8	1.3	b.d.l.
Pr	0.11	0.05	0.06	0.15	0.07	0.08	0.1	0.16	0.08	0.13	0.25	0.11
Nd	0.7	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.4	1	b.d.l.
Sm	0.2	b.d.l.	b.d.l.	0.1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.2	b.d.l.
Eu	0.08	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Gd	0.49	b.d.l.	0.14	0.19	0.14	0.10	0.16	0.30	0.07	0.20	0.29	b.d.l.
Tb	0.09	b.d.l.	b.d.l.	0.02	0.01	b.d.l.	b.d.l.	0.01	b.d.l.	0.02	b.d.l.	b.d.l.
Dy	0.83	b.d.l.	0.08	0.15	0.12	b.d.l.	b.d.l.	0.1	0.12	0.21	0.07	b.d.l.
Ho	0.26	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.07	b.d.l.	b.d.l.
Er	0.81	b.d.l.	0.06	0.12	0.11	b.d.l.	b.d.l.	0.18	0.12	0.29	0.07	b.d.l.
Tm	0.13	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Yb	0.84	b.d.l.	b.d.l.	0.12	0.07	b.d.l.	b.d.l.	0.14	0.11	0.44	b.d.l.	b.d.l.
Lu	0.16	b.d.l.	b.d.l.	0.03	0.02	0.01	0.01	0.03	0.02	0.09	b.d.l.	b.d.l.

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52 Table 3 – cjes-2017-0184suppla (continued 4)

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	Ferruginous saprolite					
Major oxides (wt.%)	GB-7A	GB-7B	K-11	GB-8B	K-18	Average
SiO ₂	1.45	3.71	15.48	2.92	1.77	5.07
Al ₂ O ₃	1.51	2.5	0.81	1.03	0.53	1.28
ΣFe ₂ O ₃	83.05	76.97	70.27	79.82	85.27	79.08
MgO	0.68	0.98	0.23	0.37	0.10	0.39
CaO	0.36	0.54	0.29	2.06	0.14	0.57
Na ₂ O	0.01	0.16	0.01	0.01	0.01	0.04
K ₂ O	0.04	0.04	0.04	0.04	0.04	0.04
TiO ₂	0.03	0.26	0.01	0.01	0.01	0.06
P ₂ O ₅	0.02	0.04	0.01	0.01	0.01	0.02
MnO	0.06	0.06	0.20	0.03	0.01	0.07
Cr ₂ O ₃	0.535	0.640	0.763	0.330	0.294	2.562
LOI	12.2	14	11.7	13.4	11.9	12.64
Total	100.10	100.35	100.00	100.17	100.04	100.13
TOT/C	0.12	0.12	0.14	0.50	0.08	0.192
TOT/S	0.07	0.04	0.08	0.09	0.08	0.07
Trace elements (ppm)						
Ba	31.7	37.4	41.5	35.2	49.2	39
Be	1	2	2	1	1	1.4
Co	30.3	41.2	148.9	17	4.6	48
Cs	b.d.l.	b.d.l.	0.4	b.d.l.	b.d.l.	b.d.l.
Ga	4.6	5.1	2.4	2.5	5.2	3.96
Hf	b.d.l.	0.8	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	b.d.l.	4.2	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	1585	3805	1732	1369	5	1699.2
Rb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Sc	3	17	14	13	12	11.8
Sr	7	11.5	7.5	11.4	7.1	8.9
Ta	b.d.l.	0.2	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Th	0.1	0.4	0.1	b.d.l.	b.d.l.	b.d.l.
U	3.1	11.8	16.3	5.2	9.3	9.14
V	137	260	49	212	148	161.2
W	5.7	27.2	0.6	1.5	0.2	7.04
Zr	3.5	22.5	1.3	2	0.6	5.98
Y	1	5.4	0.8	0.6	0.6	1.68
La	0.6	1.6	2.5	0.8	1.4	1.38
Ce	1.1	1.6	0.8	b.d.l.	b.d.l.	b.d.l.
Pr	0.12	0.32	0.12	0.06	0.07	0.14
Nd	0.6	1.4	0.4	b.d.l.	b.d.l.	b.d.l.
Sm	0.1	0.3	0.1	b.d.l.	b.d.l.	b.d.l.
Eu	b.d.l.	0.11	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Gd	0.18	0.46	0.20	0.07	0.11	0.20
Tb	0.02	0.05	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Dy	0.17	0.40	0.05	0.06	b.d.l.	b.d.l.
Ho	b.d.l.	0.11	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Er	0.11	0.38	0.08	0.06	b.d.l.	b.d.l.
Tm	b.d.l.	0.06	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Yb	0.11	0.42	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Lu	0.02	0.06	0.02	0.01	0.01	0.02
Cu	31.4	52.2	52.2	56.2	6.9	39.78

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64 Table 3 – cjes-2017-0184suppla (continued 5)

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	Ni-bearing Ferruginous saprolite						
Major oxides (wt.%)	D-11	D-12	D-13	D-14	D-17	D-19	Average
SiO ₂	28.81	20.31	55.91	44.50	43.45	22.66	35.94
Al ₂ O ₃	0.57	1.43	0.29	3.30	1.86	2.57	1.67
ΣFe ₂ O ₃	49.84	54.75	29.32	31.57	39.85	52.98	43.05
MgO	1.81	1.28	0.38	0.48	0.22	1.20	0.90
CaO	0.24	0.65	0.13	0.27	0.10	0.45	0.31
Na ₂ O	0.03	0.03	0.02	0.03	0.02	0.05	0.03
K ₂ O	0.04	0.12	0.04	0.06	0.04	0.11	0.07
TiO ₂	0.01	0.03	0.01	0.03	0.02	0.03	0.02
P ₂ O ₅	0.01	0.01	0.02	0.04	0.07	0.02	0.03
MnO	1.12	0.86	0.67	0.26	0.06	0.71	0.61
Cr ₂ O ₃	0.177	0.254	0.572	3.147	2.977	0.405	1.26
LOI	16	17.9	11	14.8	11.1	17.6	14.73
Total	99.77	99.70	99.72	99.91	99.98	99.70	99.80
TOT/C	0.09	0.22	0.12	0.14	0.13	0.09	0.13
TOT/S	0.01	0.01	0.01	0.01	0.05	0.01	0.02
Trace elements (ppm)							
Ba	517.5	824.1	276.9	125.7	63.9	102.1	318
Be	4	2	2	3	1	3	2.5
Co	996.8	1315.6	940.1	539.8	136.7	1109.1	840
Cs	5.5	7.3	1	5.7	1.2	1.7	4
Ga	0.8	2	0.8	3.4	7.7	1.6	2.72
Hf	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0.6	b.d.l.
Ni	8759	16298	11009	11036	1781	7194	9346.17
Rb	2.7	7	0.5	3.3	2	6.5	3.67
Sc	8	7	6	165	27	28	40.17
Sr	18.3	26.2	8.7	16.9	5.8	21.1	16.17
Ta	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Th	b.d.l.	0.5	b.d.l.	0.4	0.4	0.5	b.d.l.
U	3.5	2.6	6.1	25.7	3.1	6.4	7.9
V	20	31	24	238	264	32	101.5
W	0.3	0.3	0.4	0.5	0.6	0.3	0.4
Zr	1.3	4.2	b.d.l.	1.7	1	3.7	b.d.l.
Y	4.6	4.5	1.8	7.3	0.9	13.8	5.48
La	4.7	5.4	2.6	5.9	1.8	13.7	5.68
Ce	4.1	6.9	1.6	5.3	1.4	25.8	7.52
Pr	0.9	1.02	0.32	1.4	0.24	4.12	1.34
Nd	3.6	3.5	1.4	5.6	0.7	17.2	5.34
Sm	0.7	0.7	0.3	1.3	0.2	3.7	1.15
Eu	0.16	0.15	b.d.l.	0.34	b.d.l.	0.84	b.d.l.
Gd	0.79	0.69	0.28	1.05	0.22	3.11	1.02
Tb	0.11	0.10	0.04	0.16	0.03	0.52	0.16
Dy	0.66	0.65	0.15	0.90	0.24	2.9	0.92
Ho	0.16	0.12	b.d.l.	0.17	b.d.l.	0.54	b.d.l.
Er	0.48	0.42	0.15	0.66	0.11	1.45	0.55
Tm	0.09	0.05	b.d.l.	0.13	b.d.l.	0.19	b.d.l.
Yb	0.47	0.40	0.10	0.88	0.13	1.21	0.53
Lu	0.07	0.07	0.01	0.18	b.d.l.	0.16	b.d.l.
Cu	4.2	12	7	69.4	123.3	30.7	41.1

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76 Table 3 – cjes-2017-0184suppla (continued 6)

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	Silcrete					
Major oxides (wt.%)	AS-2	AS-6	AS-8A	AS-8B	AS-12	Average
SiO ₂	64.23	39.73	88.07	94.18	97.9	76.82
Al ₂ O ₃	0.03	0.03	0.14	0.03	0.13	0.07
ΣFe ₂ O ₃	4.82	1.28	8.44	3.61	0.09	3.65
MgO	0.51	0.98	0.29	0.17	0.06	0.40
CaO	15.91	31.46	0.11	0.01	0.02	9.50
Na ₂ O	0.01	0.01	0.01	0.01	0.01	0.01
K ₂ O	0.04	0.04	0.04	0.04	0.04	0.04
TiO ₂	0.01	0.01	0.01	0.01	0.01	0.01
P ₂ O ₅	0.04	0.01	0.08	0.02	0.01	0.03
MnO	0.05	0.05	0.04	0.03	0.01	0.04
Cr ₂ O ₃	0.18	0.067	0.263	0.171	0.241	0.18
LOI	14.2	26.4	2.3	1.6	1.6	9.22
Total	100.03	100.03	99.92	99.91	100.05	99.99
TOT/C	3.66	6.74	0.06	0.03	0.02	2.10
TOT/S	0.05	0.01	0.01	0.02	0.01	0.02
Trace elements (ppm)						
Ba	44.3	10.1	8.8	30.2	4.5	20
Be	1	b.d.l.	1	b.d.l.	b.d.l.	b.d.l.
Co	99.7	90.3	90.9	111.6	60	91
Cs	0.4	0.6	0.5	b.d.l.	0.2	0.36
Ga	b.d.l.	b.d.l.	0.5	b.d.l.	0.5	b.d.l.
Hf	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Nb	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	652	437	1174	646	11	584
Rb	0.9	b.d.l.	0.8	b.d.l.	b.d.l.	b.d.l.
Sc	1	1	3	2	2	1.8
Sn	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Sr	20.8	35.9	1.5	2	1.1	12.26
Ta	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Th	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
U	0.3	0.4	0.7	0.4	2.9	0.94
V	58	b.d.l.	15	11	5	b.d.l.
W	194.9	257	717	958.6	721.1	569.72
Zr	0.6	b.d.l.	b.d.l.	1.6	2.6	b.d.l.
Y	0.2	b.d.l.	0.5	0.3	b.d.l.	b.d.l.
La	b.d.l.	b.d.l.	1.2	0.6	b.d.l.	b.d.l.
Ce	0.7	b.d.l.	1.1	b.d.l.	b.d.l.	b.d.l.
Pr	0.08	b.d.l.	0.21	0.12	0.02	b.d.l.
Nd	b.d.l.	b.d.l.	0.8	0.6	b.d.l.	b.d.l.
Sm	b.d.l.	b.d.l.	0.2	b.d.l.	b.d.l.	b.d.l.
Eu	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Gd	0.07	b.d.l.	0.15	0.09	b.d.l.	b.d.l.
Tb	b.d.l.	b.d.l.	0.01	b.d.l.	b.d.l.	b.d.l.
Dy	0.05	b.d.l.	0.1	0.07	b.d.l.	b.d.l.
Ho	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Er	b.d.l.	b.d.l.	0.05	b.d.l.	b.d.l.	b.d.l.
Tm	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Yb	b.d.l.	b.d.l.	0.06	b.d.l.	b.d.l.	b.d.l.
Lu	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Cu	2.9	1.8	4.4	3.2	3.7	3.2

88
89 Table 3 – cjes-2017-0184suppla (continued 7)

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92