GEOCHEMICAL FOOTPRINTS OF IOCG DEPOSITS BENEATH THICK COVER: INSIGHTS FROM THE OLYMPIC CU-AU PROVINCE, SOUTH AUSTRALIA

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Introduction

South Australia hosts one of the world's great iron oxide copper gold (IOCG) terranes. Termed the Olympic Cu-Au Province (Skirrow et al. 2007), this belt is renowned as the host to Olympic Dam, the type example of breccia-hosted, hematite-rich IOCG deposits (Groves et al. 2003). Other significant hematite-dominated deposits include Prominent Hill and Carrapateena (Belperio et al. 2007; Porter 2010). Post-mineralisation cover, including Proterozoic to Recent rocks and sediments commonly exceed 400m and poses a significant risk and cost to mineral exploration. Exploration typically consists of single drill holes into geophysical targets.

The South Australian Geological Survey in collaboration with the Deep Technology Cooperative Research Centre (DET CRC) have undertaken a program of reassaying historic drill cores in order to identify characteristic geochemical 'footprints' of IOCG deposits under cover. The specific aim is to identify distal geochemical footprints of IOCG deposits, both within and above basement.

Methodology

Most data were obtained on samples from drill holes held in storage by the Department of State Development, with the remaining samples from company drill holes. One-metre basement intersections were sampled every 10 m, with flexibility to vary the sample spacing to gain the most representative samples. Where feasible, a sample was also taken above and below the sediment cover-basement unconformity, specifically targeting any basal conglomerate units containing bedrock fragments. Over 100 drill holes totalling >2500 samples were analysed (Figure 1).

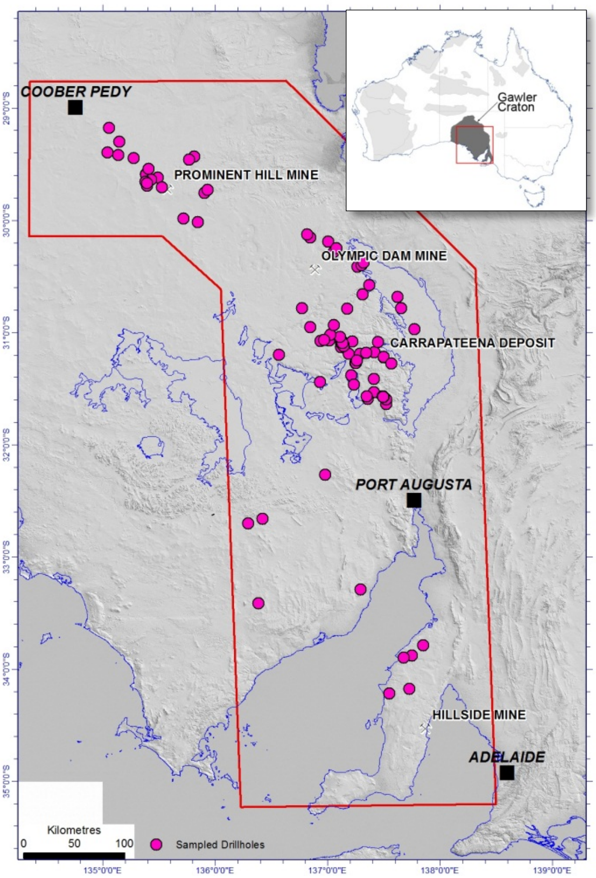

Figure 1. Location of drill holes sampled within the Olympic Cu-Au Province (red outline), Gawler Craton, South Australia.

Whole rock geochemistry

Chemical analyses on drill core samples were done by Intertek-Genalysis in Adelaide. Each sample was crushed, pulverised and analysed using the following methods;

- Lead collection fire assay on 25g samples (ICP-MS) – Au, Pt, Pd
- 4 acid (ICP-OES) – Cu, Li, Ni, Pb, S, Zn
- 4 acid (ICP-MS) – Ag, As, Bi, Cd, Co, Cs, Ge, In, Mo, Nb, Re, Sb, Se, Te, Tl
- Carbonate fusion/SIE – F
- Lithium borate fusion (ICP-OES) – Al_2O_3, CaO, Cr, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P, SiO_2, TiO_2, V
- Lithium borate fusion (ICP-MS) – Ba, Be, Ce, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Nd, Pr, Rb, Sc, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, W, Y, Yb, Zr

Spectral mineralogy

Spectral scans of drill core were made using the semi-automated hyperspectral logging tool, HyLogger^{TM}. Reflectance spectra were measured for all drill holes in visible-near infrared (400-1100 nm) through to short wave infrared (1100–2500 nm) wavelengths. Spectral data were used to interpret mineralogy using The Spectral Geologist™ (TSG) software package.

Petrophysical measurement

Drill hole sampling was accompanied by measurements of magnetic susceptibility and specific gravity. Magnetic susceptibility measurements (Terraplus KT9) were obtained every two metres and specific gravity measurements approximately every three metres. Magnetic susceptibility values of more than 0.05 SI units were used to indicate the presence of magnetic minerals.

Classification of alteration

Rock alteration in each sample was classified using a combination of spectral (HyLogger^{TM}), petrophysical and geochemical data (e.g., Figure 2; Fabris et al. 2013). Once classified, relationships between each alteration assemblage and the key economic elements were evaluated. Alteration assemblages related to Cu-Au mineralisation were established by identifying assemblages with a strong relationship to Cu and Au values of many times the average crustal abundance (Figure 3). Additional elements associations with these alteration assemblages were then determined.

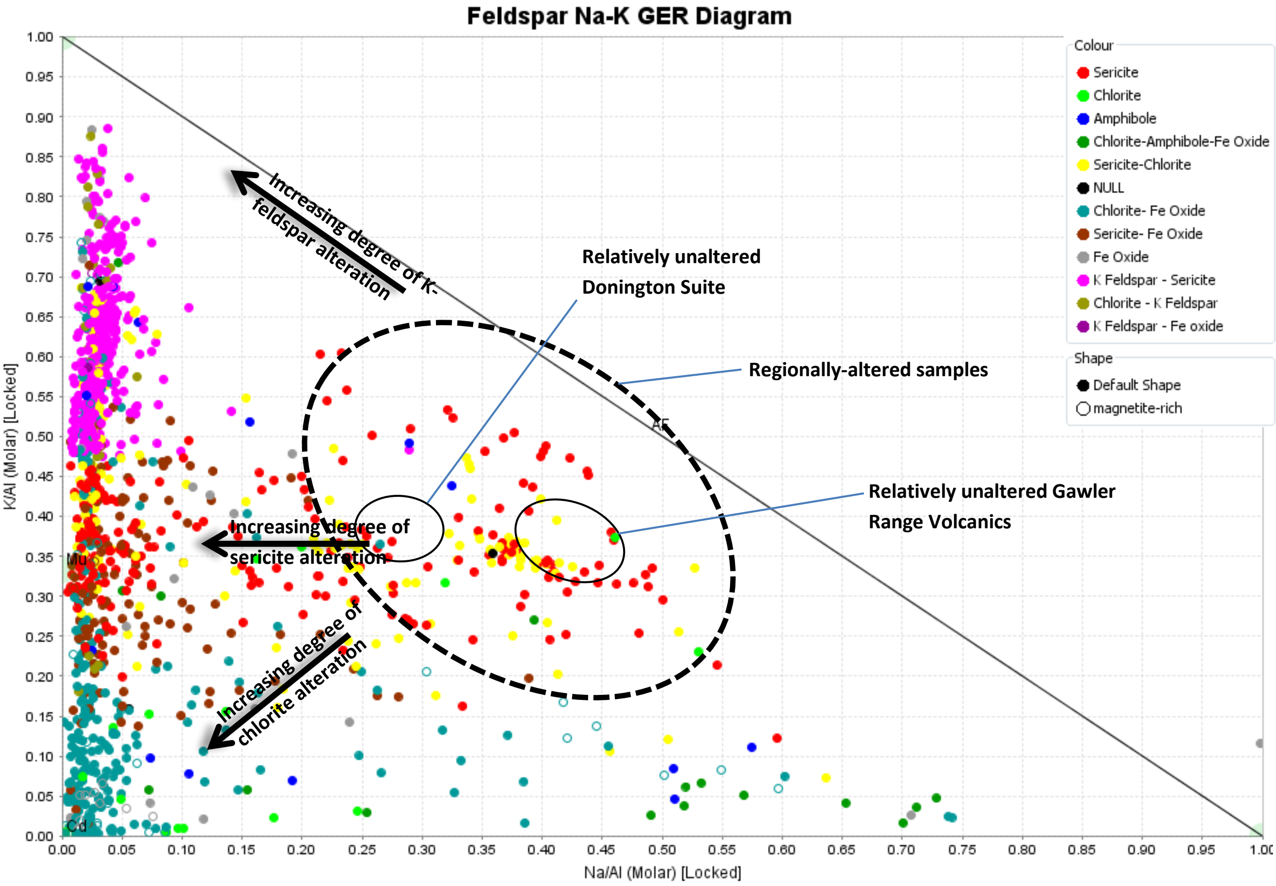

Figure 2. Plot of K/Al versus Na/Al using molar ratios. Sample points have been classified by a combination of spectral, petrophysical and geochemical data. Samples with minimal alteration have similar sodic to potasic feldspar content and therefore plot in the centre of the diagram (labelled regionally-altered samples). These can subsequently be classified as background samples. Alteration in most samples are characterised by Na depletion. The variation in K/Al commonly relate to K feldspar alteration (high values), sericite alteration (moderate values) and chlorite and/or Fe oxide alteration (low values).

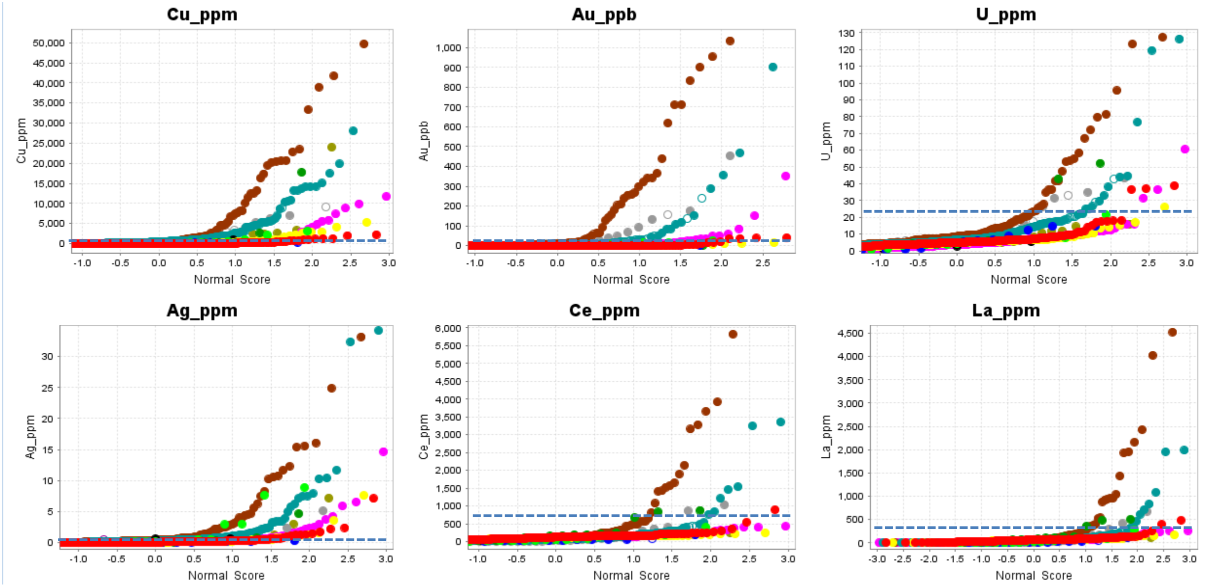

Figure 3. Probability plots for Cu, Au, U, Ag, Ce and La with respect to alteration mineral assemblages. Significant trends are those that diverge from the x-axis and other mineral assemblages. The dashed line on each graph signifies 10 times the crustal abundance for that element.

Results

Associations between elements and alteration types

Element associations with each of the alteration assemblages were examined using probability plots. In probability plots, values are plotted against the N score for each sample where N = (X-mean)/standard deviation. Elements typically associated with IOCG mineralisation (viz. Cu, Au, U, Ag, Ce, La) were enriched in the sericite-Fe oxide and chlorite-Fe oxide alteration assemblages (Figure 3). Relative to average crustal abundance (Rudnick and Gao 2003), many of the samples from the central Olympic IOCG Province are strongly anomalous in these elements.

Samples in this dataset showed strongly anomalous values for pathfinder elements (Figure 4). High W and Mo values were most commonly associated with the Fe-oxide dominated mineral assemblages (Fe-oxide, sericite-Fe oxide and chlorite-Fe oxide) and often with samples containing magnetite. Highly anomalous As, Co and Te values were most commonly associated with the chlorite-Fe oxide alteration assemblage. Values above 10 times crustal abundance for Sb, Se and Bi were typical in all alteration assemblages and were therefore not as biased towards mineral assemblages containing Fe oxide as with many other pathfinder elements in the dataset. Other elements with high values across all alteration assemblages include Ba, Cu, Ag ± W, S (Figure 4).

In addition to establishing a relationship between alteration styles and trace element anomalism, correlation coefficients and element concentrations that were many times the average crustal abundance (Rudnick & Gao 2003) were used to define the following list of elements with a relationship to IOCG mineralisation:

Au, Ag, As, Ba, Bi, Cd, Co, Cs, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Re, S, Sb, Se, Sn Te, Ti, Tl, Tm U, W, Zn, LREE (Ce, Eu, Gd, La, Pr, Nd, Sc, Sm), HREE (Dy, Er, Ho, Lu, Tb, Y, Yb)

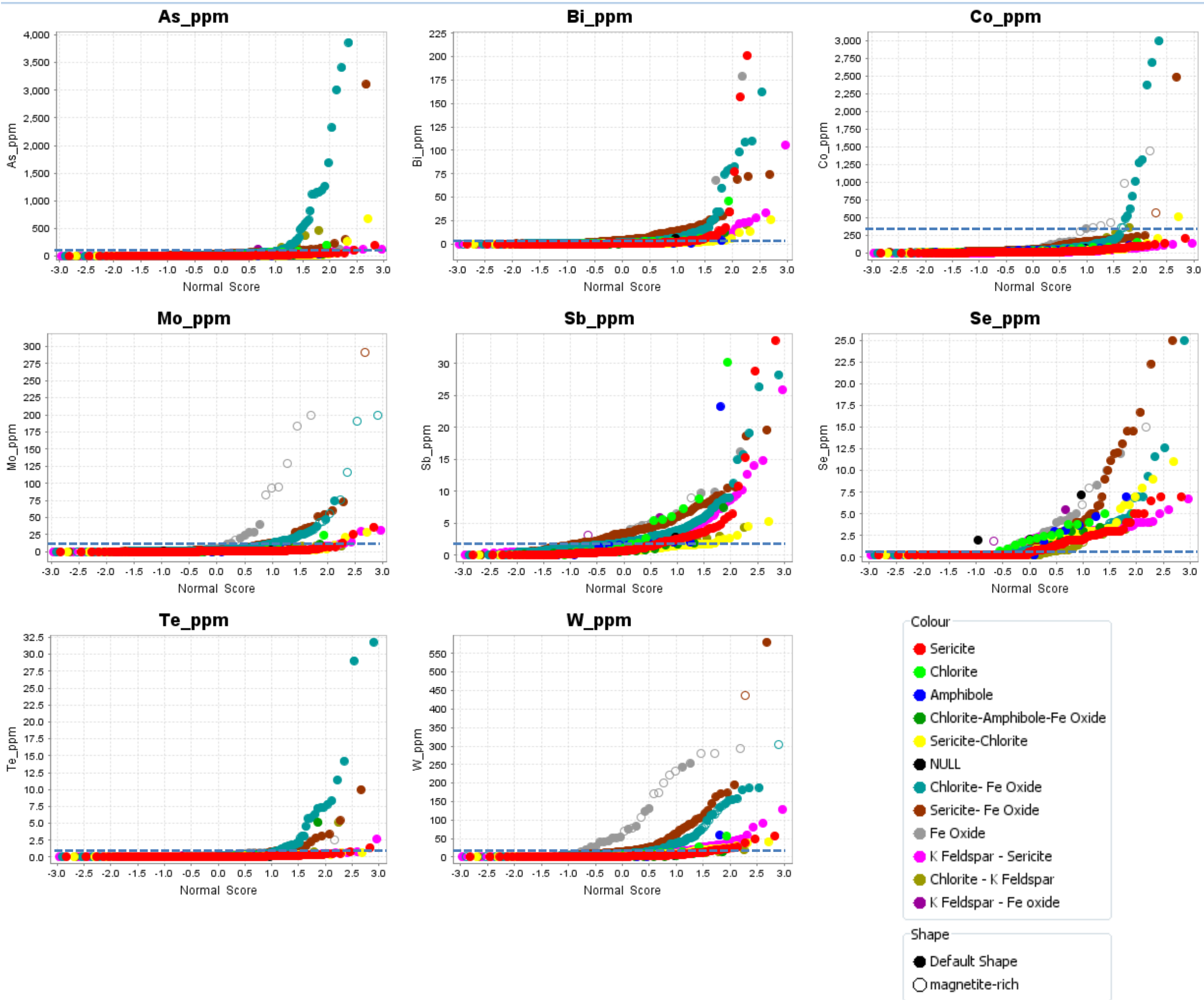

Figure 4. Probability plots for the pathfinder elements As, Bi, Co, Mo, Sb, Se, Te and W. The dashed line on each graph signifies 10 times the crustal abundance for that element. Note: some extreme values plot off the graphs.

Regional geochemical trends

The spatial distribution of trace elements associated with IOCG mineral systems within the eastern Gawler Craton were mapped in 3D (Figure 5). Around hematite-dominated IOCG systems, key associated elements were subdivided based on their distance from significant Cu mineralisation

- Local – Ce, La, Te ± Co±Cd±Mn
- Moderate – Au, Ba, Mo, S
- Broad – Bi, Ag, As, Cu, Fe, Sb, Se, W.

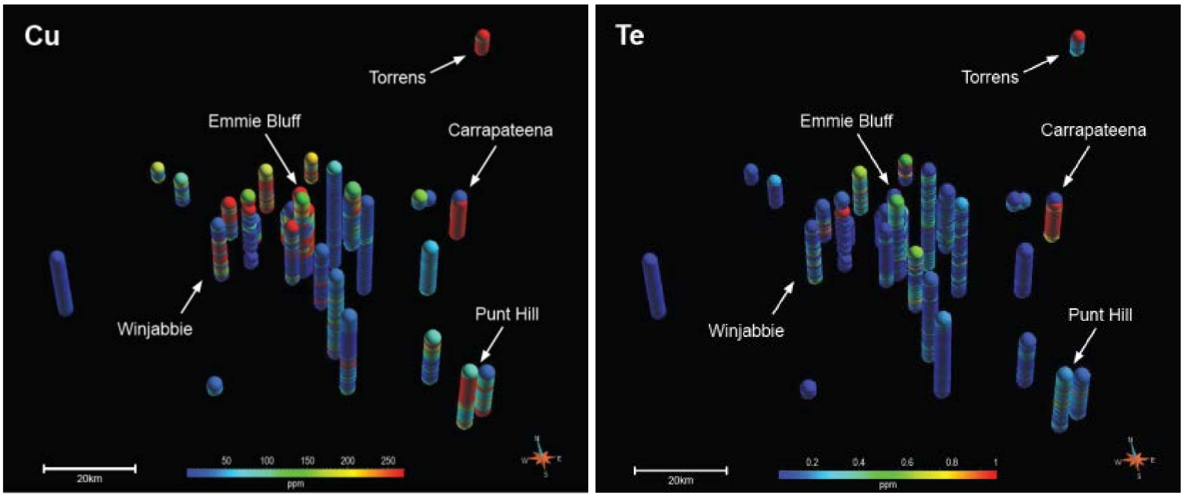

Figure 5. 3D perspective view of Cu and Te values from down hole samples, central eastern Gawler Craton, South Australia. Significant mineral occurrences are labelled. High Te values are only associated with ore grade intersections.

IOCG prospectivity Index

The recognition of size variation of geochemical halos for certain groups of trace elements that relate to Cu mineralisation in IOCG systems makes it possible to derive an index that measures how many key elements have values above a certain threshold (Fabris et al. 2013). This IOCG prospectivity index, now incorporated into IoGas v5.2, provides a method to vector using multi-element geochemical data.

Basal unconformity sampling

High values in similar elements to that evident from basement mineralisation were also found in gravel samples from just above the sedimentary cover-basement unconformity. Although geochemical trends were not as consistent as those from basement samples, the use of element combinations identified samples that were proximal to known mineralisation (Figure 6).

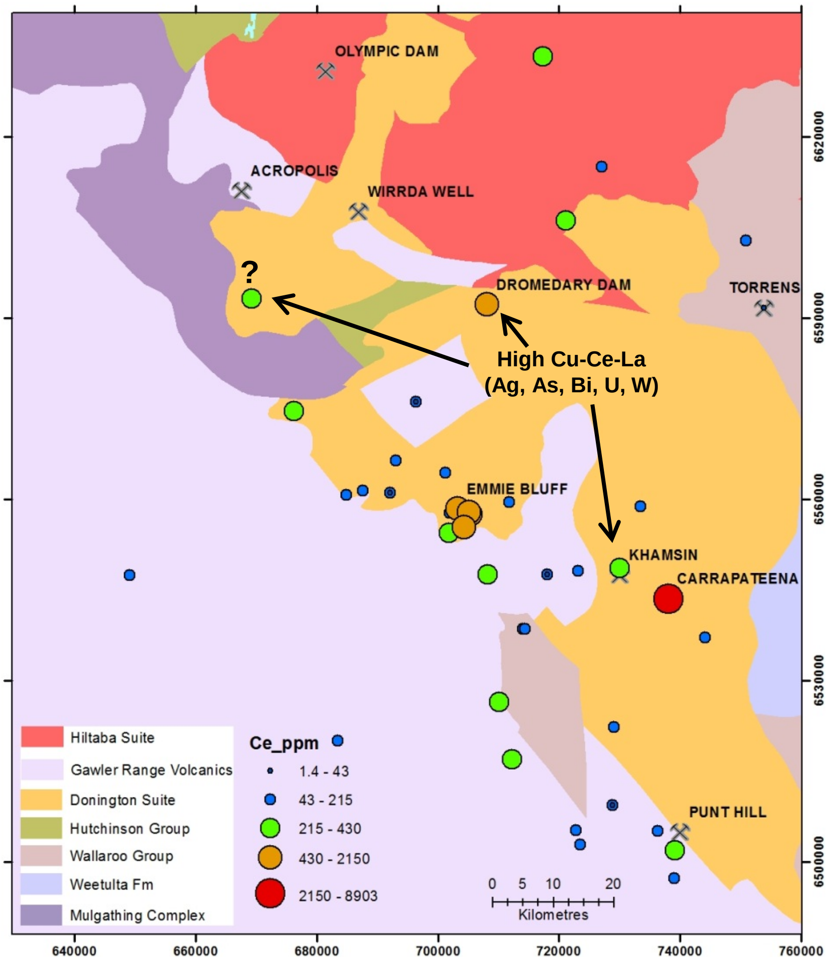

Figure 6. Ce values from base of cover sampling in the central eastern Gawler Craton, South Australia on a solid geology base map. High Ce values in combination with high Cu and La values can be used to identify proximal mineralisation within basement.

Discussion & Conclusions

Over 80% of South Australia is covered by transported regolith and these materials commonly hinder the detection of ore deposits at the surface. In addition to regolith materials, most of the highly prospective Olympic Cu-Au Province of the eastern Gawler Craton also contains several hundreds of metres of sedimentary rock which has resulted in many under explored regions, in spite of the fact that it hosts one of the world's richest orebodies, the Olympic Dam deposit. Exploration in the region has historically relied on geophysical methods. Thorough analysis of prospective basement and cover rocks by the Geological Survey of South Australia has shown that there is an important role for geochemistry in the exploration workflow and that there are coherent and very broad trace element patterns around IOCG deposits, and these can be used to recognise 'halos' within mineral systems. Samples collected from the base of the sedimentary cover-basement unconformity were found to typically reflect underlying or proximal mineralisation and provide an important sample media in areas of thick cover.

The concepts derived from this project are being tested within a ~$2M, State government funded drilling program in partnership with mineral explorers and DET CRC that is planned for mid-2015.

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